OIL-FIELD DEVELOPMENT AND PETROLEUM MINING

PLATE I.

OIL-FIELD DEVELOPMENT

AND

PETROLEUM MINING

A Practical Guide to the Exploration of Petroleum Lands, and a Study of the Engineering Problems connected with the Winning of Petroleum

INCLUDING

NOTES ON PETROLEUM LEGISLATION AND CUSTOMS AND A DISCUSSION OF THE ORIGIN OF PETROLEUM

BY

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LONDON
CROSBY LOCKWOOD AND SON
7 STATIONERS' HALL COURT, LUDGATE HILL, E.C.
1916

PRINTED AT
THE DARIEN PRESS
EDINBURGH

PREFACE.

THE rapid development of new oil-fields, and the introduction of improved types of plant and machinery to deal with ever-changing conditions, renders any work descriptive of oil-field operations subject to periodical revision. For a busy man, it is no light duty to undertake the preparation of a treatise that will do justice to the petroleum industry; nevertheless, the flattering reception afforded to, and quick sale effected of, the entire edition of "Petroleum Mining," impelled me to discharge a debt to the profession to which I am so devotedly attached.

I was profoundly dissatisfied with my former effort, and anxious to remedy deficiencies and omissions even before it had passed through the press—defects that could only be excused by the difficulty of fulfilling such a self-imposed task under excessive pressure of professional work. I, however, resisted the simple expedient of reprinting, and have endeavoured in this volume to retrieve some of my shortcomings.

Advice tendered by indulgent reviewers and sympathising correspondents, for whose suggestions I am deeply grateful, have been cheerfully acted upon, and a mass of statistical data now available to all in current petroleum periodicals has been intentionally omitted. Endeavours have been made to perpetuate throughout a practical aspect by the introduction of personally observed or authentic examples to support contentions.

and in this connection I trust that I may be excused for what may appear dogmatic conclusions on some contentious matters.

No diffidence has been felt in expressing unqualified views on certain subjects discussed, as the conclusions are based upon fifteen years' uninterrupted association with oil-field development in all parts of the world, during which time no occasion has been omitted during extensive travels to extend my sphere of knowledge, often by tedious and fatiguing journeys to remote regions, if they were likely to afford some useful information. Practical experience gained in so wide a field enables quicker and better appreciation of phenomena to be formed than is possible when energies and observation are confined to restricted areas. Likewise in the organisation and leadership of geological and topographical survey expeditions, in the valuation of producing concerns, and in the equipment and arrangement of oil properties from the time of the initial test wells to their eventual appearance as regular producers, I have had opportunities of study such as fall to the lot of few.

In the discussion of debatable subjects, I have not hesitated to draw liberally on petroleum literature, nor have I sought in vain the valued assistance of my numerous friends engaged in oil-field work in various parts of the globe. I am appreciative of the ungrudging help given me by correspondents to whom I have appealed, as well as for voluntary communications which are always warmly welcomed. I would venture here to thank correspondents for past letters, and to cordially invite correspondence or criticism from readers on any matter in this volume. It is by exchange of views, now too rare and restricted by convention, that so many subjects remain shrouded in mystery, when solutions for perplexing and obscure problems lie in some remote field known only to a few operators.

Trained as a practical engineer, an aim has been made to put in unpretentious language and concise form the main principles of an industry bristling in unsolved problems and encompassed by far-reaching possibilities, presenting unbounded opportunities for enterprising engineers of education and initiative. The training is hard, and fraught with danger of injury to health when camping in tropical forests distant from civilisation, where distractions do not exist, and long hours are the rule.

Included in this volume is a brief account of the chief oil-fields of the world, accompanied by specially prepared maps, which, it is hoped, will prove valuable for reference. The main features attaching to the leasing of oil lands are reviewed, and oil-field legislation, customs, and usages are described in some detail, and freely commented upon. The principles of refining are briefly explained, and the chief characteristics of crude oil and petroleum distillates are alluded to. A lengthy discussion of the origin of oil has been included, and special efforts have been made to explain the factors governing the accumulation and geological distribution of petroleum.

Oil-well phenomena have been minutely described under numerous sections, and remedies for defective work liberally prescribed. Engineering problems involved in oil-field equipment and development are dealt with; and the relative merits of modern plant and drilling appliances are discussed without bias. Methods of extracting oil are detailed, and a chapter has been devoted to the important subject of recording, tabulating, and analysing data for statistical purposes. Included are many diagrams and charts, graphically representing features that are less obvious in columns of figures. Some of the charts, calculated throughout from recognised formulæ, may save much trouble and time to oil-field managers.

Particular attention has been paid to the prevention of waste, both culpable and that due to inefficient working.

The debt we owe to posterity should alone check the unjustifiable waste of natural resources that has disgraced the development of oil-fields in the past. It must be remembered that, whatever the origin of petroleum, and whether oil has an adventitious or indigenous origin, no appreciable reproduction proceeds, and oil and gas fields become exhausted, just as other minerals which are mined in a more exposed way.

Absence on active service, and general disorganisation due to the European conflict, have prevented the incorporation of a certain amount of material originally intended; and for the same reason, regrettable delay in the publication of this work has been caused. I cannot express too strongly my thanks for the loyal support of my staff, Mr Geo. Madgwick, M.INST.M.M., Mr H. May, A.M.I.MECH.E., Mr R. H. May, A.M.INST.C.E., and Mr Pomeroy, M.A., F.G.S., in collecting data and preparing drawings and diagrams, and I am especially indebted to my father, Mr Beeby Thompson, F.C.S., F.G.S., for supervising the work in my absence, and for preparing most of the sections relating to the origin of oil. To Mr R. H. May I owe the working up of the section dealing with the modern adaptation of electrical power to oil properties. I particularly recognise the valuable assistance of Mr F. C. Thompson in preparing the micro- and other photographs of sands, rocks, etc., and I would be ungrateful if I failed to acknowledge the aid rendered by Mr H. D. Fletcher, in suggestions and assistance on the drilling sections during a voyage from the West Indies, and Mr James Romanes, M.A., F.G.S., for critically reading the geological section. Nothing but grateful memories arise in recording the ready assistance proffered by Dr Day and the staff of the United States Geological Survey, Washington. No request for data was ever refused, and the assistance so afforded, together with the information abstracted from the valuable technical publications of the U.S. Geological Survey, have proved of

exceptional value to me in the preparation of this volume.

To my delight, Mr Percy R. Clark, F.I.C.S., F.A.A., undertook the preparation of the chapter on oil-field organisation and accountancy, which cannot fail to prove of value to those initiating operations.

As a regular reader of British and American petroleum periodicals, I cannot fail to have drawn information from those channels that has found its way into the text, and I crave forgiveness from the editors of such journals for any material inadvertently unacknowledged.

America has at last realised the necessity of training students for an industry that is assuming such gigantic proportions, and special courses are now arranged in a number of the Universities of the country. Great Britain has not been behind hand, as besides Birmingham University, the Imperial College of Science (Royal School of Mines) has initiated a course of study. In this connection the engineering side should not be lost sight of, as oil-field development calls for engineering abilities of no mean order, if great waste of capital is to be avoided. Only an engineer can satisfactorily direct the operations of an oil company, especially where conducted in remote regions. The erection of dwellings and structures, making of roads, bridges, light railways, installation of machinery, electrical stations, telephones, the design of pipe lines, water services, etc., all call for engineering knowledge that only trained engineers can adequately supply.

It has been no simple matter to condense the contents to the limits of a single volume, but principles rather than lengthy descriptions have been kept in view. No student, who reads the book carefully, can fail to have a sound grasp of the principles underlying the vast industry of oil-field development.

CHAPTER V.

TYPICAL OIL-FIELD STRUCTURES.

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ORIGIN, COMPOSITION, CHARACTERISTICS, AND TREATMENT OF PETROLEUM.

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OIL-FIELD DEVELOPMENT

CHAPTER I.

INTRODUCTORY.

Historical — Geographical Distribution of Petroleum — United States of America — Russia — Roumania — Galicia — Germany — India — Japan — Central America—West Indies—Dutch East Indies—Persia—Canada—Africa—South America—Italy—Australasia.

Historical.—Historical references to petroleum and allied substances in literature of great antiquity prove that these widely distributed products of Nature have not only been known for many centuries, but were used in the arts long before the Christian era. Modern antiquarian exploration in Egypt and elsewhere has brought to light many objects on which native bitumen has been used in some form. The Chinese and Japanese have for centuries worked oil deposits in a primitive way, and the Parsees for over a thousand years paid pilgrimages to the "Eternal Fires" of Baku before the commercial worth of petroleum was established. Both the Incas of Peru and the Aztecs of Mexico, of which remarkable races so little is known, employed bitumen in their architecture and works of art. The medicinal properties of petroleum were recognised by the Indians of North America long before the white man set foot there, and the Persians eagerly sought certain Baku oils which were said to be endowed with curative qualities centuries before the Russians occupied the Caucasus. In both Galicia and Roumania there are old works which prove that petroleum was extracted ages before its value was generally appreciated, and the pitch well of Zante has been mentioned in classical literature.

The occurrence of petroleum has often led to the designation of towns, rivers, districts, etc. Thus, in England, there are several Pitchfords which doubtless owe their name to the local occurrence

of pitch or oil, and in Canada Petrolia is the centre of a still surviving oil industry, from which it derives its name. In Spanish-speaking countries, Brea (pitch), La Brea, Breaita, etc., are common appellations for places where oil indications are manifested; and in Persia Kir (pitch) is frequently prefixed to the names of places indicating the existence of this material. In Burma the word Yenang (earth-oil) prefixed to other words has evidently been applied to localities where there were petroleum manifestations, as at Yenangyaung (earth-oil creek) and Yenangyat, where there are now large oil developments. In Barbados, where crude oil has for over a century been exported as Barbados tar, one of the localities is called Mount All, a generally presumed corruption of Mount Oil; while in Russia such names as Neftiano, Neft (oil) are met with. Likewise in Germany we find the name of Pechelbronn (*pech*, pitch) given to a place near Hagenau where oil occurs; and on the Red Sea we find Geb-el-Zeit (head of oil), and in Algeria Ain Zeft (oil well), where there are evidences of oil. In Mexico the Indian word Chapopote is frequently found incorporated in place names where tar seepages occur; whilst in Galicia and Roumania the words Ropa and Pacura respectively have a like significance.

In India, China, and America oil was first obtained in association with brine, which was evaporated to produce salt, and often the inflammable gas which commonly accompanied the brine was directed to profitable use. In America some of the early salt manufacturers of the Kanawha district preserved the oil which rose with the salt water, and derived a small supplementary income by its sale for lubricating and lighting purposes. About the year 1820, when means were devised for drilling wells to a depth of 1,000 ft. and more, many barrels of oil daily rose with the water, and a regular trade was conducted in this "Seneka" oil.

Public interest was first aroused in petroleum as a remunerative enterprise when Colonel Drake successfully completed a well, drilled especially for petroleum, in 1859. The advent of this well led to the discovery and development of the great Appalachian oil-fields that have since furnished the world with many million tons of high grade petroleum. In 1869 the first

oil well was drilled in the Baku oil-fields of Russia, and the news of results which surpassed the most sanguine expectations or dreams was long regarded with suspicion.

Notwithstanding the abundance of petroleum found and its proved value, progress was hindered by lack of transport facilities to centres of consumption. In America and Russia the oil was conveyed in carts at great expense over bad roads to the nearest railway, and it was not until 1865 that the feasibility of piping petroleum was demonstrated in America, and ten years later before the first trunk line of any importance was constructed from near Butler to Brilliant Station on the Allegheny River, near Pittsburg. In 1879 the first great seaboard trunk line, 6 in. in diameter, was commenced from Colegrove, McKean Co., to Philadelphia, some 235 miles, with a branch 5-in. line, 66 miles long, from Millway to Baltimore.

In Russia the same transport difficulties were impeding the growth of the petroleum industry of the Caucasus, and one of the most enterprising Baku producers, following the example of America, constructed a pipe line between the Balakhany oil-fields and the Caspian seaboard at Blacktown. As in America, the carters, who had conducted a lucrative business in transporting oil, fiercely opposed the project, and for a long time it was necessary to guard the line from attacks by the disengaged carriers.

At that time the various oil products were barrelled, and exported or dispatched to their destination in that condition, but the increased trade led distributors to consider cheaper methods, as the barrels often cost far more than the contents. In 1879 Messrs Nobels, one of the largest oil producers in Russia, constructed a steamer provided with tanks for conveying oil in bulk across the Caspian Sea to the Volga where the great markets lay, and the success which rewarded their effort led to the general adoption of this means of transport on the Caspian Sea. About the same time some small ocean-going tankers were constructed, and a few years later tankships of considerable capacity were built for the conveyance of both refined and crude oil in bulk. In the year 1907 the unexpected developments in the oil industry led to many large tankers being built, the finest vessels having

a speed of eleven knots and a capacity of 6,000-7,000 tons cargo, besides bunkers for a long voyage. In 1912-13 the size of tankers was again increased to 10,000 and even 15,000 tons with success, engines being placed amidships or aft according to the design of the vessel.

Between the years 1897 and 1902 the American and Russian outputs kept very close, and for four years, 1898-1901, Russia produced about half the world's supply of petroleum, a result the more remarkable when it is considered that the Russian production was obtained from some 2,000 wells spread over an area not exceeding 10 sq. miles, whereas the other half of the world's output was obtained from tens of thousands of wells spread over many hundreds, if not thousands, of square miles of territory.

A discovery of historical interest in connection with the petroleum industry, which greatly accelerated its progress in countries where the percentage of lamp oils was small, was the method of burning heavy residual oils as fuel by pulverisation with a jet of steam or air. Until about the year 1865 there was no commercial demand for the heavy residua of asphaltic oils such as formed over 50 per cent. of Russian oils, and this product, which has for forty years dominated the price of Russian crude oils, was considered a waste product and burnt in open pits around the refineries.

Extraordinary interest was aroused in American oil enterprise in 1901-2 by the remarkably rich discoveries in California and Texas, where a new, if lower, grade of petroleum was struck in great quantities. The Spindle Top strike of Texas caused considerable agitation and excitement amongst suppliers of fuel, on account of the proximity to seaboard of a source of oil fuel whose cost was almost negligible. Ambitious schemes for distribution to European markets were, however, frustrated by the rapid fall of production when the rich area had been exploited and the narrow limits of the pool became known. About this period the Dutch East Indies developed satisfactorily.

The production of California rose so rapidly with the opening of several rich fields like Kern River and Coalinga, that in 1912 it attained the surprising amount of 12,000,000 tons (86,000,000

barrels), a total that exceeded all other oil countries. This enormous output was again supplemented by the phenomenal development of the Sunset Midway field, raising the production in 1914 to the colossal figure of 13,300,000 tons (100,000,000 barrels).

Texas provided its maximum quota of 28,000,000 barrels (4,000,000 tons) in 1905, but about the time of its decline vitality was renewed by the wonderful discoveries in the neighbouring States of Louisiana, Oklahoma, and Kansas. The Glenn pool of Oklahoma presented a striking example of the dormant wealth of these regions, and the exploration initiated in consequence of the discovery quickly brought to light other pools of high grade oil which were heartily welcomed to replace the dwindling yield of the Appalachian fields.

The yield of Galicia reached its zenith with about 2,000,000 tons (15,000,000 barrels) in 1909, owing to the tapping of some of the richest sources on the Tustanowice oil-field. Mexico started on its long anticipated career as a great exporter of fuel oils in 1911, when somewhere about 2,000,000 tons (14,000,000 barrels) were said to have been raised.

Oil enterprise received a great impetus in 1910-11 in consequence of the rapid and satisfactory development of motor propulsion and internal combustion engines for many purposes. Light distillates which had been destroyed or burnt as fuel for their disposal became the main object of refiners, and fields hitherto almost neglected became centres of great activity. Financiers readily embarked on prospecting schemes in many parts of the world, and discoveries of great value were the sequel, although the pioneers rarely derived the full benefit of their deserving energy and initiative.

About this time the striking of a well which flowed exceedingly high grade oil at a rate of about 5,000 tons (37,500 barrels) daily in the Maikop district near the Russian Black Sea coast, led to a wild land speculation which all well-wishers of the industry deplored. Thirty-two acres of the developed part of this field yielded 147,000 tons (1,100,000 barrels) in 1912. Discoveries in Persia and Egypt definitely established the existence of payable oil in these countries, and were later followed up by development

under powerful commercial groups, whose work showed that fields of great potentialities existed. Trinidad likewise was definitely advertised as an oil-field by results of some importance.

Several Russian events have placed the industry of that country on a stronger footing. One was the disclosure of rich oil deposits in the barren waste of the Urals north of the Caspian Sea, another the demonstration that along the eastern extension of the Grosny anticline rich oil sources existed at depth, and a third that the island of Cheleken in the Caspian contained rich deposits of paraffin-bearing oils.

In 1914 the feature of greatest importance was the astonishing development of Oklahoma, where the Cushing pool, only discovered in 1912, increased its output within a few months to about 5,500,000 barrels (750,000 tons) monthly, quite demoralising the oil industry of the Mid-Continental fields. Its rapid growth was no less attributable to easy and rapid drilling than to the large initial yields of the deep wells.

During the last few years several other developments have taken place, the exact importance of which is yet unknown. At Comodore Rivadavia, in the Argentine Republic, good productions of oil were unexpectedly obtained, and a field has been partially developed by the Government of that country. From the Kurokawa field of Japan has been reported a gusher which may be the prelude of important developments.

A small strike of light oil in the Calgary district of Alberta led to intense excitement and quite unjustifiable speculation in the summer of 1914. Although hundreds of companies were formed and large sums of money subscribed, no very tangible results have been achieved.

A feature of recent years has been the gradual consolidation of interests into the hands of a few powerful groups, who have sought, for obvious reasons, to distribute their investments and to control large reserve areas. Their aims have been greatly facilitated by the scarcity of transport, which often rendered it impossible to charter boats at reasonable rates to lift stocks. The cost of ocean freight has frequently exceeded the value of the oils it was desired to transport, thus effectively throttling the development of many new fields where local markets were

restricted or absent, as well as embarrassing small companies provided with only limited cash resources.

Geographical Distribution of Petroleum. — Although the commercial extraction of petroleum was for so many years confined to a few regions distributed over the world at far distant points, modern exploration and more general knowledge of the circumstances associated with its occurrence have led to the discovery of numerous oil-fields of the greatest commercial importance, and others are annually being added to a list which already extends to four continents. The increased demand for oil, coupled with improved and cheapened means of transport, is raising an average standard of value which will permit numerous fields to be remuneratively operated where previously oil could not be extracted at a profit. This especially applies to the less productive fields of high grade light oil which, until the development of motor cars and air craft, realised no higher and often a less price than heavier oils richer in illuminants and fuel oil.

The United States of America has, since 1901, been the largest producer of petroleum. Endowed with a restless and enterprising spirit, Americans could not resist the impulse of entering an industry yielding such rich rewards to the successful. Fortified by a large home demand for the product, with the added advantage of good railway communication, abundant efficient labour, and healthy climate, the industry has assumed gigantic proportions. Often stimulated by failure, the American prospector has driven his "wild cat" wells far from proved fields into regions where indications were little or nil, and thereby opened up territory which, for a century, might otherwise have remained undisclosed.

Other countries which yield large supplies of oil are Russia, Roumania, Austria-Hungary (Galicia), East Indies (Borneo, Java, and Sumatra), Mexico, and Burma, whilst important oil-fields are being developed in Persia, Peru, Assam, Trinidad, Japan, Germany, and Egypt. Smaller fields are being operated in Canada, New Zealand, Italy, and the Argentine Republic, and there are many localities where the peasants collect supplies from seepages for personal use or local requirements.

Besides the above-named countries where oil-fields are being

developed, and in some of which large undeveloped lands are known, there are important untested regions in Africa, Central and South American States, Central Asia, East Indian Islands, China, and Asiatic Turkey, where promising indications prevail, although they are often, at the moment, too far distant from transport facilities or labour centres to admit of commercial development.

Table I. shows the production of the chief oil-fields of the world up to 1914. The production must not be regarded as evidence of the maximum capabilities of the fields, even under normal development, as few products are subject to more violent fluctuations in value due to causes enumerated on pp. 55-61; and, as a natural consequence, operations in restricted areas are checked or accelerated in accordance with market conditions.

There are few countries of large extent in which indications of petroleum are non-existent, and if one includes oil shales which yield oil under destructive distillation, the number is still further diminished. Until the oil-fields themselves become exhausted, it is unlikely that the oil shales will be extensively treated, except in countries where natural supplies of oil are unknown or unimportant, and the Governments concerned foster home industries by the imposition of protective duties or granting of bounties. In Scotland alone are oil shales worked and distilled at a profit in competition with imported oils, a result attributable to highly scientific treatment, strict economy in working, and the occurrence of a large market at hand for every product.

Extensive deposits of oil shales are known to exist in France, Spain, Australia, the United States, and Canada, but only in Australia have they been worked on a large scale outside the United Kingdom.

United States of America.—In no country has there been displayed such activity in prospecting and developing oil lands as in America, where immense areas of what was regarded as almost waste land have proved to be oil-bearing territories. So rapid has been the development of the Western and Mid-Continental oil-fields of California, Kansas, Oklahoma, Illinois, and Texas, since about 1902, that the old eastern Appalachian and Lima and Indiana oil-fields sink, in comparison, almost into insignificance. Assisted by an admirable system of pipe lines, linked up with refining

TABLE I.—WORLD'S PRODUCTION OF PETROLEUM (IN METRIC TONS).[1]

Year.	U.S.A.	Russia.	Dutch East Indies.	Roumania.	Galicia.	British East Indies.	Japan.	Germany.	Other Countries.	Total in Metric Tons.
1906	16,570,801	8,168,233	1,101,334	887,091	760,443	534,101	227,532	81,350	92,839	28,419,328
1907	21,753,770	8,443,129	1,345,975	1,129,097	1,175,975	579,316	268,129	106,379	391,737	35,193,507
1908	23,387,084	8,484,840	1,386,650	1,147,727	1,754,022	672,938	276,124	141,900	719,412	37,970,697
1909	23,995,384	9,177,120	1,474,751	1,297,257	2,076,740	890,202	268,321	143,244	574,369	39,897,388
1910	27,451,842	9,557,155	1,495,715	1,352,289	1,762,560	818,400	257,421	145,168	673,735	43,514,285
1911	28,468,714	9,072,614	1,595,000	1,544,072	1,458,275	800,000	280,000	140,000	1,100,000	44,458,155
1912	29,096,832	9,325,894	1,478,132	1,806,942	1,187,007	989,801	222,854	134,784	2,518,860	46,761,106
1913	33,126,164	9,246,942	1,534,223	1,885,225	1,087,286	1,000,000	...	...	4,171,947	52,051,787
1914[2]	38,000,000	9,180,000	1,800,000	1,787,245	700,000	1,100,000	...	...	5,200,000	57,767,245

[1] From statistics prepared by the *Moniteur du Petrole Roumain.*

[2] Approximate.

centres and ports of shipment, and stimulated by large home markets, the oil industry of the States has attained an importance and magnitude surpassed by few other industries.

It has been officially estimated by the United States Geological Survey that there are in the United States some 8,850 sq. miles of known oil-bearing territory, made up as follows:—

	Sq. Miles.		Sq. Miles.
Alaska	500	Missouri	30
Alabama	50	New Mexico	80
California	850	New York	300
Colorado	200	Ohio	650
Idaho	10	Oklahoma	400
Illinois	200	Pennsylvania	2,000
Indiana	1,000	Tennessee	80
Kansas	200	Texas	400
Kentucky	400	Utah	40
Louisiana	60	West Virginia	570
Michigan	80	Wyoming	750

Appalachian Oil-Field.—From 1859 to 1875 this field gave the entire American production of oil, and until 1885 still furnished 98.5 per cent. of it. It then began to assume less importance, until at the end of 1913 it represented but 10.43 per cent. Its maximum yearly production was 36,000,000 barrels (4,800,000 tons) in 1900, and in 1913 it had fallen to 26,000,000 barrels (3,470,000 tons), yet over $14,000,000 more was paid for the smaller quantity. The great rise in prices in 1912-13 sufficed, by encouraging exploitation, to turn a normal decline of 5-6 per cent. in the production of Pennsylvania into an increase of 1.6 per cent. Similarly the State of New York showed an increase of 3.21 per cent. in 1913, instead of the usual 7-8 per cent. decline. Both of these increases represent rather increased attention to the cleaning of wells than the bringing in of new areas. On the other hand, West Virginia, being newer territory, cannot definitely be said to have yet passed its maximum; in 1913 a decrease of 4.63 per cent. represented the falling off in the Blue Creek pool production, which had led in the previous year to a heavy increase. Eastern Ohio production declined 1 per cent. in 1913, after a rise the previous year succeeding a steady decline for a number of years, the maximum for that state as a whole having been reached in 1896.

The Appalachian field stretches along the eastern side of

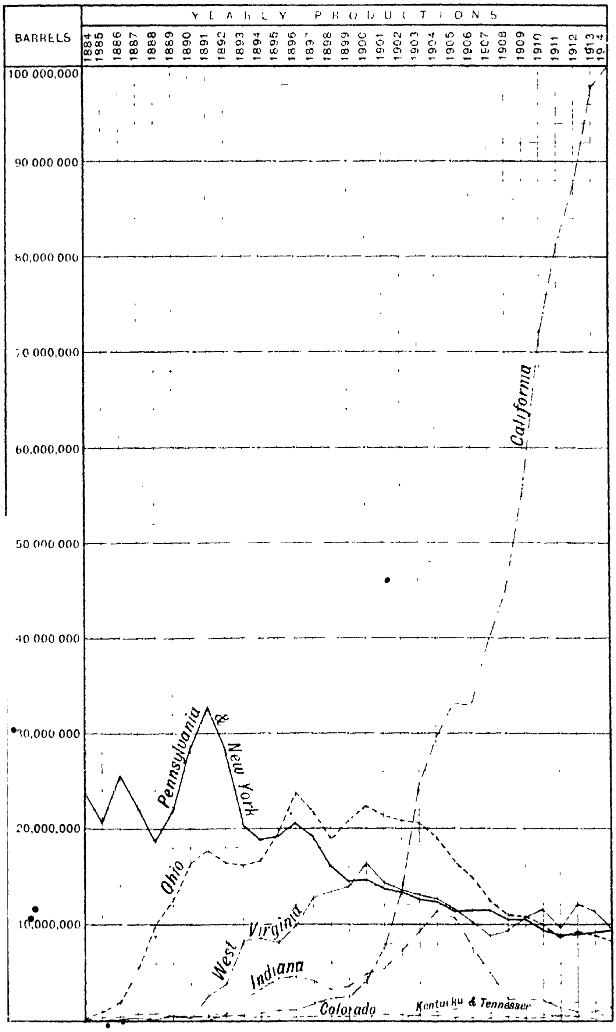


Fig. 1.—Chart Showing Production of Petroleum Oil-Fields in U.S.A.

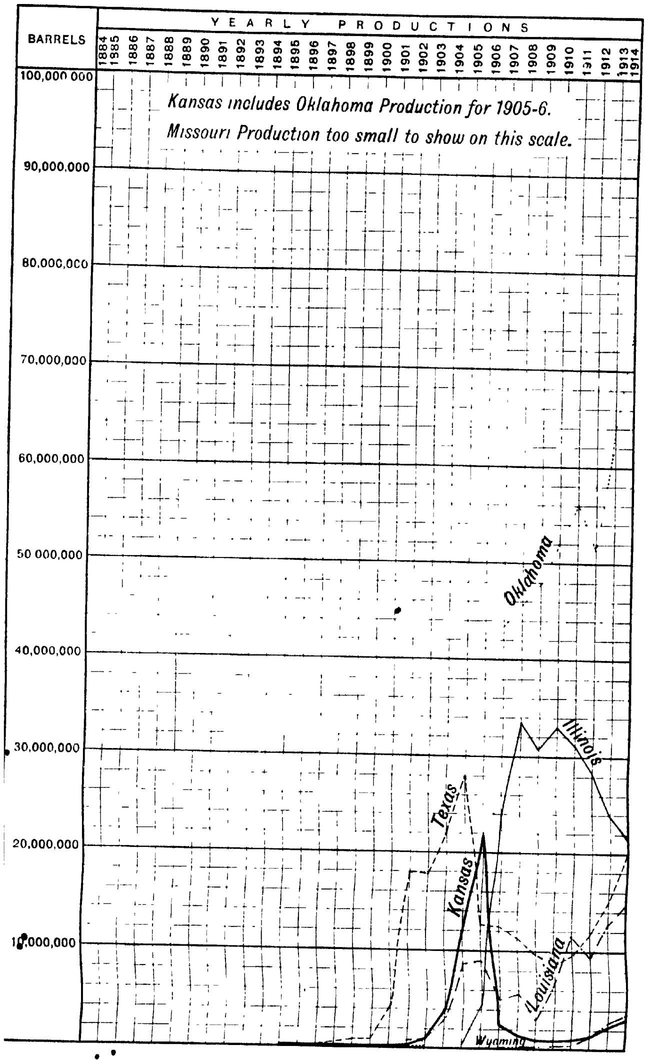


FIG. 1a.—CHART SHOWING PRODUCTION FROM OIL-FIELDS IN U.S.A.

[To face page 10.

the Allegheny Mountains in a north-eastern direction, and is coincident with the geosyncline lying between these mountains and the big Cincinnati anticline. The nearly horizontal character of the strata throughout most of the area gives rise to steep and often very narrow and tortuous valleys, along which outcropping coal seams or other marked horizons may often be followed for considerable distances. It was in this country that in 1859 was born in Oil Creek, Venango Co., Pennsylvania, the modern industry of large scale oil production by means of drilled wells. The above quoted maximum production for the Appalachian field in 1900 was due to the help of West Virginia. The old Pennsylvania-New York area reached its maximum with 33,000,000 barrels (4,400,000 tons) in 1891.

Various attempts are made to group the oil districts of Pennsylvania and New York, which vary from time to time. The chief divisions are:—

(*a*) The *Bradford* district in the northern part of McKean Co., and which extends into Cattaraugus Co., New York. Development began in 1875; it reached its maximum in 1880. The productive sand is called by drillers the "third sand," although Carll showed it to be 1,000 ft. below the Oil Creek "third sand." The oil is amber, green, or black, and is usually heavier than that of the lower field.

The Allegany district of New York may be included with the Bradford.

(*b*) The *Warren Co.* area is situated in the east of Warren Co., and the north-east of Forest Co. It includes the Cherry Grove, Balltown and Cooper, Stoneham, Clarendon, Tiona, Kane, Grand Valley, and other pools. The oil sands are coarser than in the Bradford area, often containing pebbles, and belong to the Chemung group of the Devonian. The oil is usually amber in colour.

(*c*) The *Lower Field* includes Venango Co., where the oil industry of the United States started, some pools in south-west Warren Co., Clarion, Butler, Armstrong and Beaver counties. The Venango Co. oil is from the first, second, and third sands, white or yellowish conglomerates formed of pebbles loosely cemented with fine sand. The oils are green, sometimes black,

and often amber, with gravity .875-.773 (30°-51° B.). The third sand is richest, and its oil has a density of .786 (48° B.). Clarion, Butler, and Armstrong counties yield from the same sands. Beaver Co. has the Slippery Rock and Smith's Ferry fields, yielding heavy oil from the Pottsville Conglomerate, and amber oil from the Pithole Grit.

(*d*) *South-West Pennsylvania* includes Greene, Washington, and Allegany counties. Washington Co. had its first well drilled in 1885 on the Gantz Farm. This continued in production till 1911. The wells are in the Gordon and fifth sands, but the Gantz and 50 ft. sands were better producers. The oil has a paraffin base, is usually green in colour, sometimes black. In Greene Co. the most important area is Mount Morris, which forms the northern continuation of the Mannington pool in West Virginia. Here the Big Injun sand first appears. Some very deep wells occur in Greene Co., one being 5,322 ft.

It is worthy of note, as regards these old fields of the United States, that no pool has been entirely abandoned as exhausted, and wells are still being pumped within a few yards of the original Drake well at Titusville, Pa. As an illustration of the staying powers of these fields, one can quote the instance, given in the "Production of Petroleum in 1912" of the United States Geological Survey, of 300 acres of land in Butler Co., including twenty-four producing wells, changing hands at a price that approximated $2,250 per barrel of daily production. Again, in 1911, the same authority mentioned the Triangle well on the edge of Scio township in Allegany Co., New York, as being still pumped, although it was the first commercial well drilled in New York in 1879. It then (1911) yielded an average of about one-eighth barrel per day. In spite of the drain caused by these wells on the oil contained in the sands of the old pools, wells drilled since the rise in price of oil in 1913 have often yielded excellent production from locations between the old wells. There is therefore no question of rapid exhaustion of these fields.

West Virginia.—The West Virginian fields form the south-western continuation of the Pennsylvanian and eastern Ohio fields. The greatest production so far attained was in 1900, with 16,000,000 barrels (2,100,000 tons); the subsequent decline was partly made

good in 1912 as was noted above. The oil-bearing counties are Monongalia, Marion, Tyler, Wetzel, Marshall, Wirt, Kanawha, Clay, Lincoln, Pleasant, Doddridge, Harrison, Lewis, Gilmer, Ohio, Calhoun, Wood, Ritchie, Roane, Cabell, Boone, Brooke, and Hancock. The more important pools may be grouped as follows:—

(*a*) The continuation through from Pennsylvania of the Mount Morris district in Monongalia and Marion counties, the richest neighbourhood being at Mannington, the Big Injun sand being highly productive at a depth 1,176-1,322 ft. below the Pittsburg coal, with a thickness of 145-235 ft. The oil is amber in colour, gravity .786-.777 (48°-50° B.).

(*b*) Tyler and Wetzel counties, where in the former county in 1891 the Sistersville pool was located in the Big Injun at 1,100 ft. below the Ohio River. This pool extends to both sides of the Ohio River, and may also be reckoned as the southern continuation of the McDonald pool in Washington Co., Pa. In 1897 many wells reached the Gordon sand. Just above this is the Gordon stray, which is a prolific gas sand. Wells in the Big Injun sand gave 20-200 barrels, and gas wells up to 18,000,000 cub. ft., with rock pressure in some cases of 800-1,200 lbs. Pittsburg is supplied by the gas.

(*c*) The Volcano and Eureka districts in Wood, Ritchie, and Pleasant counties.

(*d*) The original West Virginian oil-fields in Wirt Co., where drilling commenced as far back as 1859, and oil was struck in the Dunkard sand at 303 ft., and the Gordon sand lies at a depth of over 2,000 ft. The oils are usually green in colour, and in the upper sands have a sp. gr. of .820 (41° B.), whilst in the Big Injun, between 1,300-1,400 ft., oil, with a gravity of .770 (52° B.), is met. The field has been extended through smaller pools in Roane Co. into the Blue Creek pool in Kanawha Co. which came into great prominence during 1911-12.

Further south-west some small pools of good oil in Berea Grit and Big Injun sands have been opened up in Cabell, Lincoln, and Wayne counties.

Central and South-Eastern Ohio.—Included in the Appalachian area are the central and south-eastern counties of Ohio, viz., Morgan,

Washington, Monroe, Hocking, and Perry counties, whilst of lesser importance are Jefferson, Harrison, Belmont, Noble, Fairfield, and Licking. The area is usually divided into the shallow sand district of Macksburg, Marietta, and Chester Hill in Washington and Noble counties, which is pretty well defined, and the deep sand territory which, if somewhat expensive drilling for the average production yielded, offers more scope for "wild-catting." Production from shallow sands commenced in the Macksburg district in 1859, and in Chester Hill and Buck Run in 1860; in 1877 the Berea Grit was reached at 1,400-1,500 ft. by deeper wells in the Macksburg district. To the north in Monroe Co. various pools have been developed, including the Sistersville in 1890, where the Big Injun sand is worked, the pool being continuous with that in the West Virginian fields. Modern developments began with the advent of pipe lines in the early 'nineties, a maximum production having been reached in 1903, with 5,500,000 barrels (730,000 tons); in 1913 it still remains nearly 5,000,000 barrels (670,000 tons).

The decline in the natural gas supply in North West Ohio led, in 1909, to efforts to open up sources in the Clinton sands further east, and in doing so new oil pools were discovered in this formation, at first in Fairfield Co., and then in Perry Co. This activity soon extended into Hocking, Muskingum, Licking, and the adjacent counties. This deep sand development has since become the mainstay of south-eastern Ohio production.

Kentucky and Tennessee.—The most southerly extension of the Appalachian area lies in the States of Kentucky and Tennessee. Production on a small scale proceeded for many years, but development dates from 1900, after which production grew rapidly to 1,200,000 barrels (160,000 tons) in 1905, since when it has declined, amounting to 500,000 barrels (66,000 tons) in 1914, the latter figure representing Kentucky production only. Since 1908 no production has been returned from Tennessee. A number of small pools have been developed; those in Lawrence and Morgan counties form the continuation of the West Virginian fields, the oil being found in the Berea Grit, and attempts are being made to continue these developments into Bath, Wolfe, and Estil counties.

On the southern border, in Wayne Co., is centred the main production of the state, whilst important pools are developed further west in Allen and Barren counties. The oil obtained from the Devonian corniferous limestone at Ragland, in Bath Co., is heavy, not unlike Lima oil, as is also the oil of Allen and Barren counties, whilst that of Wayne and adjacent counties approaches more to Pennsylvania grade, with sp. gr. .820-.840 (41°-37° B.), and is dark green in colour. In Ohio Co. high grade oil was struck in 1912, and is of interest as forming a link with the Illinois and Indiana field.

Lima-Indiana Oil-Field.—Lying to the north-west of the Appalachian field, the oil is derived from the Trenton limestone, which is occasionally dolomitised to afford a sufficiently porous rock. Beginning at Findlay in Hancock Co., in North-West Ohio, in the year 1884 development was rapid, and next year was marked by the great extension in use of natural gas in the United States, with which industry these fields were primarily associated, and in 1885 oil was struck at Lima, in Allen Co., and production increased rapidly, the sulphur oils here obtained being first successfully treated at the Toledo refinery in 1889, and excellent products are now obtained, including paraffin wax. In 1889 oil was first obtained in Indiana in Wells Co. The 1886 production of 1,000,000 barrels (140,000 tons) increased to 25,000,000 barrels (3,450,000 tons) in 1896. The subsequent decline was accentuated by the opening up of the Illinois fields, in 1907-8, which attracted operators from Lima-Indiana; nevertheless, the great rise in price of crude oil did not enable this decline to be entirely stemmed even in 1913, when a production of only 4,700,000 barrels (650,000 tons) was obtained. Three grades of oil are recognised, viz., North Lima, South Lima and Indiana, and Princeton; Indiana, the first-named, obtaining the best price.

The bulk of the North-West Ohio production comes from Wood Co., where development began in 1890 at Montgomery, and the oil is rather lighter than elsewhere, having a gravity of .814 (42° B.). Further east a second pool occurs. The Findlay district in Hancock Co., and Lima in Allen Co., are important producers, and also Sandusky Co. with the Gibsonsburg-Helena field, whilst lesser pools have been worked in Van Wert, Mercer, Seneca, Ottawa,

Auglaize, Lucas, Putnam, Wyandot, Shelby, and Darke counties. Practically all the oil is obtained from the Trenton limestone. In Indiana also the bulk of the oil comes from the Trenton limestone in the north-east corner of the state, and forms the more direct extension of the Lima field; it is found in Sullivan, Adams, Wells, Huntington, Grant, Blackford, Gay, Madison, Delaware, and Randolph counties; and less important pools occur in Wabash, Miami, Hamilton, and Marion counties. In the corniferous limestone (Devonian) unimportant oil is found at Terre Haute in Vigo Co., at Birdseye in Dubois Co., at Salem in Washington Co., and north-west of Medarysville in Jasper Co., and from the Huron sandstone (Lower Carboniferous) near Princeton in Gibson Co., with more recent developments in 1913-14 at Sullivan Co.

Illinois Oil-Field.—For many years productive in a very small way, it was only in 1905 that drilling near Casey Co. led to extensive developments, first in the shallow field, and then rapidly extending southwards into Cumberland, Crawford, and Lawrence counties; smaller areas in Coles and Edgar counties were also found productive. Already in 1907 and 1908 symptoms of exhaustion in the shallow sands of Clark, Coles, Cumberland, and Edgar counties became apparent. The deeper fields of Lawrence Co., with six distinct sands had better staying powers, and in 1912 were extended south into Wabash Co. In 1909 the Centralia-Sandoval field was opened in Marion Co., and other districts were tested on likely structures, but so far the La Salle anticline is the only one giving large production. The oil is found in domes along the La Salle anticline, which also extends into Indiana, and is productive at Princeton, the formation being Carboniferous. In quality it improves further south, being thick, asphaltic, and sulphur-bearing in the shallow sands. From 1st January 1908 to 20th December 1912, Illinois oils were graded and sold according to gravity, but this system was then abolished. The maximum production was reached as early as 1908, with 33,686,000 barrels (4,700,000 tons), that of 1913 amounting to 23,893,000 barrels (3,300,000 tons). In the early days large tank farms were erected to cope with the huge stocks carried by the pipe lines; these stocks in 1910 exceeded 99,000,000 barrels (14,000,000 tons).

By the end of 1913 these stocks had sunk to about 8,000,000 barrels (1,100,000 tons).

Mid-Continental Oil-Field.—This embraces a very large area. Kansas has developed twenty-five oil and gas pools in the following counties:—Franklin, Miami, Coffey, Anderson, Linn, Greenwood, Bourbon, Allen, Woodson, Wilson, Neosho, Sumner, Cowley, Chautauqua, Montgomery, and Labette. Although production on a small scale had proceeded for many years, it was in 1904 that Kansas first came into prominence with over 4,000,000 barrels (550,000 tons). Its output afterwards declined to about a million, but rose again during 1912-13 to 2,375,000 barrels (330,000 tons) in the latter year. This was due to increase of drilling coincident with the rise in price of crude oil, and the low cost of leases in Kansas, as compared with Oklahoma, caused much attention to be given to the former state.

Oklahoma contains the southern extension of the Kansas field, and its production, which came into prominence at the same time as Kansas, rapidly outstripped it in amount, and reaching 56,000,000 barrels (7,700,000 tons) in 1911, fell to 51,400,000 barrels (7,000,000 tons) the next year, to rise again sharply in 1913 to 63,579,000 barrels (8,800,000 tons), and in 1914 to 98,000,000 barrels (13,000,000 tons). This increase was partly due to the phenomenal Cushing pool, which was exposed in 1912. Towards the end of 1914 its capacity was estimated at about 250,000 barrels (34,000 tons) per day through the remarkable results attending the development of the Bartlesville sand. Many other districts contributed, including the Osage, the extension of the Hogshooter pool to the east, and of the shallow fields to the west; the developments between Bartlesville and the old Dewey pool; the developments in the immediate neighbourhood of Tulsa, and the new Wicey pool near Mounds. A new district in 1913, which became of importance in 1914, was the Healdton, Carter Co. The older fields are in the lands of the Cherokee, Osage, and Creek nations.

The development of Kansas and Oklahoma is an interesting study of rapid growth beyond the capacity of pipe lines and subsequent reaction in price of crude oil, over-production being accentuated by the inclusion of drilling obligations in Indian leases; a rapid rise in price always follows any symptom of the

pipe lines being able to cope with the production, for the refining companies are anxious to ensure their being able to work at full capacity.

The Electra field in northern Texas has increased steadily from 1911, and in 1913 had a production of 8,000,000 barrels (1,100,000 tons). A promising field was brought in during 1913-14 at Moran, in Shackelford Co. These oils are of high grade. The Corsicana district gives the heavy oil of the Powell pool, and the lighter oils in the immediate neighbourhood of Corsicana itself. Henrietta (Clay Co.) and Electra (Wichita and Wilbarger counties) average about .819 (41°B.), and show practically no sulphur or asphalt. The Electra, Petrolia, and Henrietta fields are located in the great belt of Permian "Red Beds" in northern Texas. In Louisiana the Caddo field is characterised by its variable production, which, since 1906, has increased to 9,781,000 barrels (1,300,000 tons) in 1913. A district that has come prominently to the fore is De Soto parish, but with the spread of development work other pools are likely to be discovered.

Gulf Field.—This includes a great number of scattered pools in southern Texas and Louisiana, characterised by their production of an oil of an asphaltic nature with sulphur, the geological conditions differing from other American fields in that the oil is always associated with salt domes. From such pools the maximum production is soon reached, and then a steady decline ensues. The pools which have so far yielded important production in Texas are Batson, Dayton, Matagorda, Humble, Saratoga, Sourlake, and Spindle Top; and in Louisiana, Jennings, Welsh, Anse-la-Batte, and Vinton. Many similar salt domes exist, but those tested have not yielded oil in payable quantities. The Gulf field first came into prominence in 1901, reached its maximum with 36,500,000 barrels (5,000,000 tons) in 1905, and declined, first rapidly, then irregularly, until in 1913 it remained practically constant at 8,500,000 barrels (1,200,000 tons). At the close of 1913 the tendency to drill deeper in the vicinity of the various salt domes of the Gulf field led to the striking of good gushers, approaching in dimensions those of the early days of the field, in which Sourlake had led the way. This practice led to the production of a higher grade oil, green in colour.

Californian Oil-Fields.—Since 1909 California has yielded the largest production of any state in the Union, a position it formerly held from 1903 to 1906. In 1913 it reached nearly 100,000,000 (97,788,525) barrels (14,000,000 tons). Although essentially a region of asphaltic oils, used orginally as fuel, deeper drilling in the Coalinga district of late has resulted in the discovery of higher grade oil containing paraffin: and improvements in refining have led to the general introduction of topping and dehydrating plants, affording improved fuel in addition to other valuable products. The fields lie scattered in the coastal region north of Los Angeles.

After a small production, chiefly of heavy fuel oil, for many years in Ventura, Santa Barbara, Los Angeles, and Fresno counties, oil was discovered near Bakersfield in Kern Co. in 1899, and the Kern River field rapidly developed. This encouraged prospecting in many parts of the state, and rapidly increased the production of the Coalinga field in Fresno Co., and developed the Santa Maria field in Santa Barbara Co

Before this time much prospecting had been carried on in the western side of the San Joaquin Valley, developing the Sunset, Midway, and McKittrick fields. Meanwhile the Sherman, Whittier, and other limited pools in and near Los Angeles had developed significant production. In 1910 and 1911 oil was discovered in the La Habra Valley and in the Lost Hills and Elk Hills. In 1912 large wells of unusual depth were developed in La Habra Valley field, with large gushers in the valley fields, but a decline in the old Santa Maria field was registered. Natural gas was piped from the valley fields to Los Angeles, and gasoline was largely extracted from natural gas. About this time the Standard Oil Company withdrew from the purchase of oils heavier than .946 (18° B.). 1913 saw no new pools discovered, but a number of large gushers within well-known oil pools, particularly in the Maricopa-Midway-Sunset and Fullerton fields. In this year no less than forty-eight wells were completed in California with initial yields exceeding 1,000 barrels (say 140 tons) per day, and at least five in the Maricopa-Midway-Sunset field came in at initial yields of 10,000 barrels (1,400 tons) and over.

Official returns give the number of producing wells in California

at the end of 1913 as 6,817, of which number Kern River claimed 1,778.

The chief oil-fields of California are:—

County.	*Oil Fields of Importance.*
Los Angeles	Los Angeles City, Newhall, Puente, Salt Lake, Sherman, Whittier.
Orange	Fullerton.
Ventura	Santa Paula.
Santa Barbara	Lampoc, Santa Maria, Summerland.
San Luis Obispo	
Santa Clara	
Fresno	Coalinga.
Kern	Midway - Sunset - Maricopa, Kern River, McKittrick, Lost Hills.

Six to eight inch diameter pipe lines have been constructed from the more important oil-fields to the coastal refineries and shipping ports. From Kern River and Sunset oil-fields there are four 8-in. pipe lines leading to San Francisco Bay, distances of 284 and 279 miles respectively, besides numerous connecting lines. Four 8-in. pipe lines connect the Santa Maria oil-fields with Port Harford. 8-in. lines, 154 miles long, connect Los Angeles with the Midway field, and another takes the production of the Los Angeles oil-fields. Other lines run to Monterey from Coalinga, 110 miles, from Orcutt to Port San Luis, 32 miles, and El Segundo from Puente Hills district, about 23 miles.

California fuel oil is transported to the Pacific coast ports, both northwards to Vancouver for railways and industries, and southwards as far as Chili for the nitrate "oficinas." Panama has been a consumer in the past, and will doubtless continue to be the centre of an important oil-bunkering trade.

Minor Oil-Fields.—*Wyoming.*—Since the year 1910 the production of Wyoming has made rapid strides, stimulated by the rise in price of oil, as well as by the increased transport facilities. In 1910 it amounted to 115,000 barrels (16,000 tons), whereas in 1914 it had risen to 4,500,000 barrels (620,000 tons), the centre of the industry being located at Salt Creek, near Casper, in. National Co., with another considerable development in the Big Horn district at the opposite side of the state.

Colorado.—Having yielded a fluctuating amount for many years, the maximum of 820,000 barrels (110,000 tons) being in 1892, the

PLATE IV.

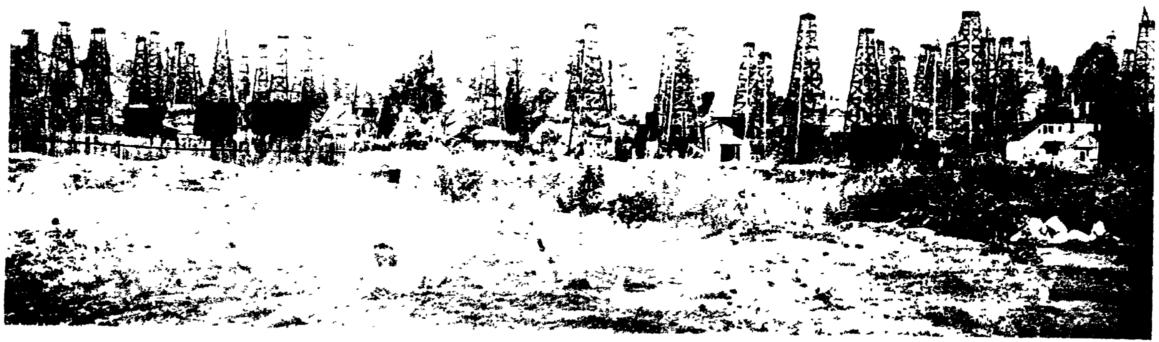


FIG. 2.—VIEW OF LOS ANGELES OIL-FIELD, CALIFORNIA.

A typical illustration of an oil field located on a sharply inflected anticline where the width over which wells can be profitably drilled is confined to narrow limits.

production of the State of Colorado declined to 150,000 barrels in 1914, the bulk of this coming from the Florence field.

Russia.—*Baku Oil-Fields.*—The oil-fields of Baku attained world-wide fame in consequence of the prodigious yields of individual wells at a time when such great outputs were unknown elsewhere. Single wells have for weeks yielded daily an output equal to the total annual production of many oil-fields elsewhere, where hundreds of wells were being regularly exploited.

Two of the world's greatest oil-fields lie within a few miles of the old Tartar city of Baku. The Balakhany-Saboontchy-Romany field occupies an area of about 2,640 acres on a plateau a few miles from the Caspian Sea; the Bibi-Eibat field is located in a secluded bay on the Caspian Sea coast, about 2 miles south of Baku, and covers an area of approximately 1,000 acres. Both these fields make a striking impression upon a visitor, as the large number of separate oil sources and the numerous small land holdings have led to an extraordinary congestion of derricks. About the year 1901, from these two fields of less than 4,000 acres was derived more than half the world's production of petroleum.

Very great difficulty has been found in drilling wells in the soft Tertiary clays and sands from which the oil is abstracted, and wells of 2,000-2,500 ft. cost £10,000 ($50,000) or more to complete, and require a starting diameter of 36-40 in. to ensure the requisite depth being attained with a workable size.

Since 1908 the Surakhany district, to the south-east of the Romany oil-field, has been methodically drilled with marked success. The field was first operated for gas which saturated the shallow sands, the product being led to the oil-fields for burning beneath boilers. At one time as much as 16,000,000 cub. ft. of gas was daily piped from Surakhany for this purpose. Sometimes quite large supplies of white oil, sp. gr. .785, were struck in association with the gas, but the limited demand for light spirit gave this wonderful oil no increased value. Deeper drilling, however, divulged the presence of the typical dark Baku oils, and work is now mainly confined to the exploitation of these sources, which have proved exceedingly prolific.

In the neighbourhood of Baku other small oil-fields have been developed to some extent, including Binagadi, where in 1912

245,000 tons (1,750,000 barrels) of oil were raised. There are numbers of known localities of great promise in the Apsheron district, and the natural exhaustion of the old fields already being felt will inevitably lead operators to test these areas, and compel the authorities to decide disputed titles which now embarrass prospectors. No better prospects exist anywhere than in some of the areas visited by the author in this part of the Caucasus.

The oil from the Balakhany-Saboontchy-Romany-Surakhany oil-field is pumped to the refineries at Blacktown, a suburb of Baku, whilst Bibi-Eibat oils are conveyed by barge across the bay to the same spot. The main outlet for products is the Caspian Sea and River Volga, the latter, however, being closed for navigation on account of ice during four months of the year.

The Caspian-Volga trade is unique in several respects. The southern parts of the Caspian are in mild climates, and the water never freezes, but the northern parts suffer from an Arctic winter, and the sea and river are frozen up. In the open months the accumulated stocks from Baku are hastily transported in tankers to the Astrakhan roadstead, where they are transferred to barges for conveyance to Astrakhan, and thence to points on the Volga. The extensive delta makes it necessary to execute this work about 100 miles out at sea, where a floating marine town springs up with customs, police officers, shipping agents, medical ship, and other accessories of a typical shipping port.

In 1897 the Russian Government commenced the construction of an 8-in. pipe line from Baku to Batoum on the Black Sea, to relieve the congestion of traffic on the railway to that port. This line, completed in 1905, has a capacity of 1,000,000 tons (7,500,000 barrels) of kerosene a year, and affords the one outlet for Russian oils to the main ocean highways. The Transcaucasian Railway is capable of transporting about 1,500,000 tons (11,200,000 barrels) of petroleum products per annum, the joint facilities, consequently, enabling Russia to export some 2,500,000 tons (18,700,000 barrels) of oil products from the Apsheron oil-fields.

Grosny Oil-Field.—The second field of importance in point of view of production is that of Grosny, which, in 1914, yielded

PLATE V.

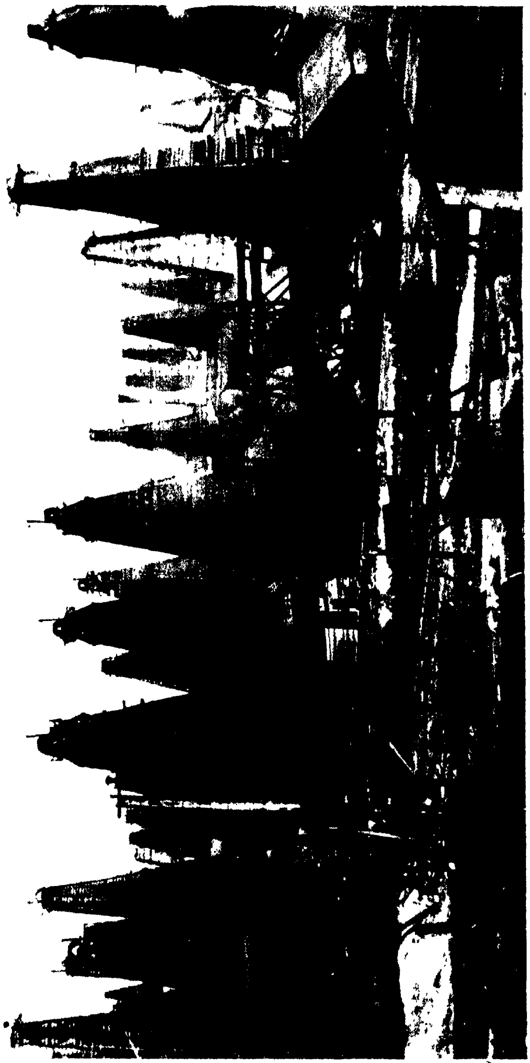


FIG. 3.—VIEW OF BIBI-EIBAT OIL-FIELD OF RUSSIA.

[To face page 22.

1,300,000 tons (9,500,000 barrels) of oil from an area of approximately 8,000 acres. The first well was sunk in the early 'nineties, by an Englishman, Mr Alfred Suart, and the field has never falsified the hopes of its pioneers. Situated near to the main railway line to the Caucasus, and conveniently located for export facilities to both Novorossisk on the Black Sea and Petrovsk on the Caspian, it benefits from a choice of outlets which are capable of great development with the aid of pipe lines so far only projected.

The strata are much more compact and less liable to cave than those of Baku, enabling wells to be sunk much quicker and more cheaply. The structure also differs from that of Baku, and the oil-fields follow for many miles a narrow belt along the flanks of a ridge, rising from the valley of the Terek. In 1912 an extension of the Grosny oil belt was proved at Bellik, where exceedingly productive wells were struck near the crest of a nearly symmetrical anticline.

The refineries are erected along the railway near the town of Grosny, to which pipe lines from the field conduct the oil by gravity.

On the neighbouring parallel range of Sunja there are excellent indications of oil, which have, so far, been left unprospected, but which will one day certainly develop important fields.

Ural Caspian Oil-Field.—The existence of a field of no mean potentialities has been proved in an area north of the Caspian Sea, and inland from the port of Guriev. Fierce summer heat, intense winter cold, scarcity of potable water, and absence of transport facilities, have combined to delay the development of this area, which had been proved by small operators many years ago. Exceedingly prolific wells have been struck near Dossor, and the field is capable of great developments.

Two 6-in. pipe lines have been constructed to Bolshaya Rakushka where refineries have been built, and oil is conveyed from thence to the Russian markets *via* the Volga. Owing to shallow water, submarine pipe lines have had to be laid to where steamers can lie in safety.

The total concealment of the oil-bearing series beneath old Caspian Sea deposits over most of the area is a serious hindrance

to geological study, rendering elucidation of the structure difficult and slow.

Cheleken Oil-Field.—South of the port of Krasnovodsk, in the Transcaspian provinces, lies the island of Cheleken, for centuries renowned for its wonderful display of asphaltic and ozokerite seepages and deposits. Involved structures and inconsistent results have dispirited many enterprising operators, but during the years 1911-14, in the region of Ali Tepe to the south-west of the island, exceedingly satisfactory results have been achieved, and wells of great yield have been struck at moderate depths. Endeavours to extend the limits of a somewhat confined area have hitherto failed, and the fate of the island as a great oil-field is still uncertain.

Cheleken petroleum is rich in paraffin wax. The crude is shipped to Baku for treatment in the Blacktown refineries. The production of the island reached a maximum in 1912, with 209,000 tons (1,500,000 barrels), and in 1913 it was 129,000 tons (950,000 barrels).

Maikop Oil-Field.—A belt fringing the northern flanks of the western extension of the Caucasus Mountains has, for years, been the centre of a peasant oil industry. In 1909 a field of considerable productivity was revealed near Shirvansky, where several initial wells, only 281 ft. deep, yielded up to 50,000 tons (375,000 barrels) of high grade oil. The limits of the rich pool proved to be restricted along the strike, and never justified the large capital that was spent upon the undeveloped portions of the field; and the mining regulations, framed on the basis of the Baku oil-fields, were such as to discourage prospectors to explore far afield along the belt of indications. On 23rd March 1915 a large gusher was brought in at a depth of 1,320 ft. on plot 457, which lies about a mile down the dip, in relation to the horizon of the original Shirvansky wells.[1] Up to 1915 the oil-field had given an output of about 500,000 tons (3,750,000 barrels) of oil. Pipe lines were constructed to Ekaterinodar and the port of Touapse on the Black Sea, and refineries were built at Ekaterinodar and Shirvansky.

Central Asiatic Oil-Fields.—Excellent prospects were exposed

[1] This well gave within nine months 70,000 tons (525,000 barrels) of high grade oil.

in developing an area in the Fergana district of Turkestan. Paraffin-bearing oils were struck at workable depths in some quantity, and in 1906 the output of the field reached 64,000 tons (450,000 barrels). No great energy appears to have been displayed in following up the initial success, although the oil was largely sought for by the Government railways for fuel and freight.

The area covered by the oil formations is very great, and oil seepages are known to exist on both sides of the Hissar Mountains. The Bokhara side is remote, but the deposits in many respects are similar to those of the Fergana fields.

Many areas in the Transcaspian province give favourable indications of oil, but difficulties of transport, inaccessibility, and doubts concerning disposal of output, have discouraged prospecting. Those adjoining the Caspian shore near Cheleken have received slight attention considering their interesting character.

Small Russian Oil-Fields.— On Holy Island, lying off the northern coast of the Apsheron peninsula, a regular development has been proceeding for many years. Oil is obtained in payable quantities, and either barged to the Blacktown refineries for treatment, or added direct to liquid fuel cargoes proceeding to the Volga. The last officially returned yield was 94,000 tons (680,000 barrels) in 1914.

Berekei, a district on the Caspian Sea shores, a few miles north-west of Derbent, attracted great attention in 1903, on account of the striking of several highly prolific wells that gave initial yields of 300-700 tons (2,000-5,000 barrels) daily. Water troubles arose that appeared insurmountable, and eventually most operators abandoned the field after it had produced from 50,000-75,000 tons (375,000-565,000 barrels) of oil.

At many spots in the Caucasus remarkable and unmistakable indications prove the existence of oil in large quantities, and in many cases trial wells have already demonstrated the fact. These areas are often held on insecure tenure, or located so unfortunately for transport of plant and materials and subsequent disposal of products that business men decline to proceed further at the moment. In the Taman peninsula, around Lake Baikal, in the Uchta district of Archangel, and on the Russian part of Sakhalin, oil has been discovered.

Roumania.—*Bushtenari Oil-Field.*—Along the southern and eastern flanks of the Carpathian Mountains, which make a sharp sweep and form the northern and western boundaries of the country, many spots had been the centre of a small peasant oil industry long before the scientific extraction of oil was entertained. The first field to attract widespread attention by its richness was Bushtenari, which, until 1909, yielded the main supplies of the country, and established the reputation of Roumania as a safe source of oil supply. The oil of Bushtenari was of an asphaltic base, but rich in illuminants, which were for years the main objective of Continental refiners.

Campina Oil-Field.—Interest was next diverted to Campina, some 4 miles westward of Bushtenari on the same anticline, where immense productions of paraffin-bearing oils were struck at inconsiderable depths. Like Bushtenari, this field is yielding declining productions, the deep wells failing to respond like the upper sources.

At many points between these two fields oil in less quantities has been, and is being extracted, the main centres being at Doftana, Calinet, and Țelega, where the oil is of an asphaltic base. To the south of this extended field of operations water led to spasmodic and irregular results, which scared cautious operators, but in 1911 a subsidiary fold was located at Chiciura, along which some very productive wells have been struck in both an easterly and westerly direction. Active operations were, in 1912-13, initiated at Chiciura, Gropi, Runcu, Grausor, and Tonteshti, and there is every evidence that this line will connect up with Bordeni, a field to the eastward, which has yielded large supplies of oil especially rich in benzine contents.

Moreni Oil-Fields.—One of the great surprises of the country was Moreni, where a clearly defined anticline was known to exist, and where a peasant industry had long been conducted by operating hand-dug shafts. Wells drilled to depths of 1,000-2,000 ft. have yielded prodigious supplies of oil, and wells of 100,000 tons (750,000 barrels) capacity have not been uncommon. One well, between 1912-14, yielded 400,000 tons (3,000,000 barrels) of oil, and as its advent synchronised with high prices it probably constitutes a world's record for remunerative reward.

PLATE VI

FIG. 4. VIEW OF THE BUSHTENARI OIL-FIELD OF ROUMANIA.

To face page 26.

To the west of the Moreni (Stavropoleos) field is Gura Ocnitza, where satisfactory though not startling development has continued for many years, and to the east is Moreni (Bana), which has puzzled geologists and operators by the many peculiar features it presented. Here, in addition to the proving of oil on the southern flanks of the anticline as at Moreni (Stavropoleos), a shallow field of strictly limited proportions was opened up on the northern flanks, where wells gave often 5,000-10,000 tons (37,000 barrels to 75,000 barrels) of oil containing as much as 40 per cent. benzine. The discovery of this field at a time when benzine was in great request, created quite a sensation, as sales could be readily effected on the spot at £4 per ton ($2.50 per barrel), when initial yields of 100 tons (750 barrels) daily per well were not uncommon. Deeper drilling at Bana in 1914 disclosed the existence of paraffin-bearing oils in a different geological horizon, and large flowing wells were struck.

Filipeshti-Baicoi Oil-Fields.—Along the same anticline several other fields of commercial importance have been located. At Filipeshti de Padure, 5 miles east of Moreni, where a perfect symmetrical anticline is observable, paraffin oils are struck at a depth of 3,000 ft., but the high cost and lengthy process of drilling act naturally as a deterrent to producers of modest means, especially as wells have proved on the whole somewhat disappointing. At Baicoi and Tsintea, 4½ and 7½ miles east of Filipeshti, startling results have alternated with bitter disappointments, which in turn attract and repel operators from the field. The structure of both fields is so intricate, and the uncertainties so pronounced, especially at Baicoi, that only those endowed with the greatest optimism and ample resources have been induced to test their luck. Cheapened methods of drilling and a few good strikes are attracting renewed attention to the Baicoi field.

Baicoi oil is in demand on account of its richness in light products, but Tsintea oils are heavy, and usually realise 40-60 per cent. less in the market than the standard varieties.

Buzau and other small Oil-Fields.—The Beciu oil-field, in the province of Buzau, has attracted attention on account of the sustained though small yield of individual wells and the exceptional quality of kerosene the crûde oil yields under distillation. The oil

issues from compact strata instead of loose sands, as in mos Roumanian oil-fields.

Other oil-fields of uncertain value have been disclosed at th following places:—Moineshti, Solonti, Zemes, Tetcani, Campeni an Casin in Bacau, Sarata and Berca in Buzau, Glodeni and Ochiur in Dambovita, Apostolache, Popeshti, Vulcaneshti, Poiana, Pacureti and Matita in Prahova; but although the presence of petroleum has been demonstrated, and geological conditions justify a certain amount of optimism, the results are not yet sufficiently conclusive to classify the areas under proved oil-fields.

The oil industry of Roumania is mainly centred at Ploeshti, a town of 50,000 inhabitants, around which the main refineries of the country have been located. To this town there is a system of private and public pipe lines from all the important oil-fields, with inter-communication between the refineries. The Steaua Romana refinery, of a capacity of about 2,000 tons (15,000 barrels) daily, is at Campina, and at Tchana Voda on the Danube there is also a refinery, besides one or two at Targoviste.

Realising the injury suffered by a progressive industry in the absence of free facilities for export, the Government has at length undertaken the construction of a trunk pipe line to Constanzia. For years the whole of the export oil, except such as was taken by neighbouring countries, was conveyed by tank wagons on the Roumanian railways to Constanzia, but the congestion of traffic and scarcity of tank cars was stifling the growth of one of the chief industries of the country.

The port of Constanzia is on the Black Sea, 170 miles from the main oil-fields of the country, and is destined to become increasingly important in the near future. A very perfectly designed oil port and storage installation was constructed at Constanzia when the magnitude of the oil business was first realised by the Government, but with the pipe-line connection exporters will naturally prefer to transfer their refineries to the coast.

Foreign capital has played an important part in the development of the Roumanian oil industry, there being large investments by English, French, German, and Dutch capitalists.

Galicia.—The rapid expansion of production in Galicia, following on a long extended gradual growth, and succeeded

by a rapid decline, has drawn much attention to these most interesting fields.

Oil was known for a very long time, and appears to have had its uses recognised as early as the eighteenth century, towards the end of which a production of 7 tons per annum is recorded, obtained entirely from seepages or shallow excavations. Between 1810-17 burning oil was successfully distilled from the crude, but attempts to create an industry came to nothing, and the real founder was A. Schreiner, who, in 1853, with the aid of some Lemberg (Lwow) chemists, established small refineries at various centres.

Hand drilling was introduced at Boryslaw in 1862, and at Bobrka in 1863, and in 1867 A. Fauck began using the cable system at Kleczany. The difficulties due to disturbed geological conditions were not lessened by the scarcity of good casing, and it remained for the Canadian system, as brought by W. H. MacGarvey in 1882 to Kryg, to enable real progress in drilling to be chronicled. The old one metre square hand-dugs could attain a depth of 100 m. (328 ft.); the old cable drilling rarely achieved more than 200 m. (656 ft.), but the Canadian system has been modified and adapted, so that wells have now been drilled little short of 6,000 ft. Galician oil-fields require deep and expensive drilling. In 1913 there were in Boryslaw-Tustanowice 252 wells over 4,000 ft. deep.

The production, which in 1882 had grown steadily to 45,600 tons (330,000 barrels), reached 71,600 tons (515,000 barrels) in 1889, and then in 1902 a test well was drilled at Boryslaw to 3,000 ft., a district where the early activity in shallow oil had, during the 'sixties and 'seventies, given place to a feverish "fossicking" after ozokerite. The result of this well was a 3,000 barrel gusher, and Galician production progressed by leaps and bounds, passing the million tons in 1907, doubling this figure in 1909, and falling back to it again in 1913. This meant that Boryslaw and its extension, Tustanowice, absorbed all attention of Galician operators and in 1908 produced 95.3 per cent. of the total production; in 1913 the ratio was only 82.5 per cent.

The rapid progress in production referred to above subjected the industry to the problem of a large excess production above the

needs for home consumption, and quantities had to be exported. Attempts to regulate the export trade by the formation of "cartels" among the refinery owners have all hitherto proved failures. The price of oil declined from the earlier 'nineties, being then about 7 kr. per 100 kg. (nearly £3 per ton), and in 1907 had become critical with a minimum price of 80 h. (about 7s. per ton). In 1911 the lowest price reached 60 h. (5s. per ton). To aid the industry, the Government was prevailed upon in 1910 to erect a large topping plant at Drohobycz, with a view of utilising the residuals as fuel on the State railways and in the Austrian Navy. They purchased in 1910 819,700 tons (5,900,000 barrels), thus drawing on the previous year's stock to the extent of 600,000 tons. This refinery has a capacity of 500,000 tons (3,600,000 barrels) per annum, which, however, has not been attained, the maximum throughput of 372,000 tons (2,700,000 barrels) being in 1912. In 1913 the State railways partially abandoned the use of liquid fuel. Another important influence on the market was created by the formation of the Union of Producers to store and market the crude oil produced, which has not been subject to the vicissitudes of the "cartels." Producers sell their crude oil to the Union, or if they are refiners as well, the excess of their production only, receiving a certain proportion of the price in cash, the balance to be received when the annual accounts are made up.

These influences came into play just when the highest production had been reached. The result was a steadying up in prices, followed by their inflation, and a turning of the producers back to the neglected outlying fields, particularly at Bitkow to the east, and around Krosno in western Galicia. Large amounts of capital were invested here in 1912, 1913, and to the beginning of the war, much of which had seen no return up to the latter date.

Eastern Galician Oil-Fields.—Boryslaw-Tustanowice.—Boryslaw was well known for its seepages, and was the source of the oil for early refinery experiments. More particularly, the 1853 developments led to a demand for oil, and a consequent sinking of hand-dugs. The first drilled well was in 1862, and about this time the value of the ozokerite met with in the hand-dugs, was realised, leading, as we have seen, to loss of interest in Boryslaw

as an oil centre. The Canadian system was introduced in 1896, early wells being drilled to 1,500 ft., and henceforward developments were rapid, leading to deep drilling in 1902, extension to Tustanowice in 1904, and growth of production as has already been seen. The Boryslaw anticline, an asymmetric fold much subjected to strike and also dip faulting, with older formations thrust over the productive Oligocene, pitches to the east under Tustanowice, Truskawiec, and Dobrohostow. In Tustanowice oil has been struck at 5,000 ft., whilst before the war wells were being drilled further east to 5,800 ft. and over.

The production nearly doubled itself in 1907, whilst the maximum was reached in 1909, with 1,700,000 tons (12,000,000 barrels) for Tustanowice, and 230,000 tons (1,700,000 barrels) for Boryslaw. In 1911 serious water trouble was met with in certain parts of Tustanowice, doubtless aided by the big strike faults, leading to rapid decline, so that in 1913 the Tustanowice production was only 691,000 tons (5,000,000 barrels), and Boryslaw 205,900 tons (1,500,000 barrels). Boryslaw oil is very rich in paraffin, is a good oil of .850-.860 gravity (34-32° B.); it forms the standard market grade for Galicia, the price of other districts fluctuating accordingly.

South and south-west of Boryslaw-Tustanowice lie two parallel but less productive oil zones, *Mraznica-Orow*, 2 km. away, and *Opaka-Schodnica-Urycz*, 4.5 km. further on. Both are producing, Mraźnica giving oil very like Boryslaw, but without as much paraffin, and of .873 (30° B.) gravity, whereas in Schodnica oil of variable gravity and colour is found, often with considerable paraffin contents. In 1914 deep drilling was proceeding along both zones. The production in 1913 was 29,550 tons (212,000 barrels) from Schodnica; whilst Urycz and Mraznica gave 8,000 tons (57,000 barrels) and 1,600 tons (11,000 barrels) respectively. Drilling was commenced at Schodnica in 1894, although for twenty years previous, production had been obtained. In 1900 the Schodnica-Urycz production reached 185,000 tons (1,330,000 barrels), since when it has gradually declined.

Bitkow.—Next in importance to Boryslaw-Tustanowice in 1913 was the production of *Bitkow*, situated west of Nadworna, in a very hilly district in south-eastern Galicia. Production has proceeded

since the spring of 1899, but since 1911 more attention has been devoted to it, and with considerable success. The production of 1913 was 36,700 tons (275,000 barrels), a 13 per cent. increase on the previous year. The oil, which is high grade, with gravity .764 (53° B.), comes from a depth of 1,800-2,000 ft., and is worth double the price of Boryslaw oil. *Pasieczna*, 3-4 miles south-east, was for many years the site of small production, whilst northwards lie *Starunia*, *Maidan*, and *Dzwiniacz*. At Starunia-Dzwiniacz are ozokerite deposits occupying a corresponding position in this field to Boryslaw in the last mentioned one. *Sloboda Rungurska*, at one time the chief producer in Galicia, lies east of the railway; and still further towards the Bukowina is Kosmacz, with a production of 2,460 tons (18,000 barrels) in 1913. The Sloboda-Rungurska production declined from 1887, and in 1913 was only 3,460 tons (26,000 barrels).

Western Galician Oil-Fields.—There are many fields, some of which have in the past given fair yields, others small, but which have received much more attention since 1912. An important group of fields lies around Krosno.

Bobrka.—The first field to be exploited systematically was Bobrka, gradually extended through *Wietrzno*, *Rowne*, and *Rogi*. It lies some 7-8 miles south of Krosno, and oil has been worked at Bobrka for over fifty years from a compressed anticline in Oligocene beds, the first well being drilled in 1863. The Canadian system was introduced into this field in 1885, and production increased rapidly, many flowing wells being obtained from deep sources. In Rowne one well reached 3,600 ft. The oil has a gravity of .870 (31° B.). The production, which in 1904 was 57,280 tons (410,000 barrels), when Rogi was at its best, fell to 8,000 tons (57,000 barrels) in 1913.

Potok.—Potok, lying north of Krosno, is one of the good fields of Galicia. An Eocene anticline pitches north-west from *Toroszowka* to Potok, and gushers were common in it. The production in 1902 for the whole field was 32,500 tons (234,000 barrels), and in 1913 it had fallen to 12,750 tons (92,000 barrels). The oil is brown with a gravity of .800-.850 (45°-34.5° B.), gives 22 per cent. benzine and 50 per cent. kerosene. A pipe line connects to the station at Jedlicze. South-east of Toroszowka lie

Kroscienko-Nizne and *Wyzne*, which produced 5,600 tons (40,000 barrels) in 1913, and a fluctuating amount of like order for many years. A short distance north-east lie *Zmienica* and *Turzepole*, with an Eocene fold which gave 2,500 tons (18,000 barrels) in 1913; and still further north-east is a line of Cretaceous inliers in Eocene rocks. At one of these inliers, *Weglowka*, a production of 7,500 tons (53,000 barrels) was obtained in 1913, whilst in 1906 it was 11,860 tons (85,000 barrels). The inliers extend south-east in the direction of *Sanok*, as far as *Grabownica*, and have been worked in a small way at shallow depth, yielding very high grade oil. The only other locality giving any notable production in 1913 in this zone was *Humniska*, with 2,300 tons (17,000 barrels); in 1904 it gave 5,200 tons (37,000 barrels).

Midway between Sanok and Chyrow lies a field with production at *Wankowa*, *Brelikow*, *Leszczowate* and *Ropienka*, of 17,800 tons (128,000 barrels) in 1913. It had 36,000 tons (260,000 barrels) in 1901. There is here a compressed Eocene anticline between Oligocene folds.

South of Sanok lies the *Zagorz*, *Wielopole* and *Tarnawa* field, much faulted and with complex structure. Many but short-lived gushers have been obtained, usually from a depth of 1,600-2,300 ft., and are much subject to the influence of fissures. After being worked during the early 'nineties, the field was abandoned, but has since been restarted, the production in 1913 being 4,850 tons (35,000 barrels).

Gorlice District.—Between Jaslo and Gorlice are many fields, mostly lying east of the railway. Much of the early history of the Galician oil industry was here evolved, the first refinery being built, as we have already noticed, at Kleczany, in 1858, by Ignaz Lukasiewicz. *Kleczany*, the most westerly field in Galicia, was still producing 20 tons (150 barrels) in 1913. It yields an amber coloured oil with 15-20 per cent. of vaseline, a production of one barrel per month being profitable to work. The wells are long lived; its maximum production was 840 tons (6,000 barrels) in 1897.

The Canadian system of drilling was first employed in Galicia at *Kryg* in 1882, and for many years the Gorlice district remained the principal one in Galicia, the bulk of the Gorlice production

being still obtained around Kryg at *Kobylanka, Libusza, Lipin, Dominikowice* and *Mecina Wielka*, which together produced 10,0 tons (73,000 barrels) in 1913; the only other important producti in these parts in that year came from *Klimkowka*, south of Gorli with 7,100 tons (52,000 barrels), where considerable drilling intere is now centred, wells having depths of 1,500-1,800 ft., and *Harklowa* and *Pagorzyna*, south of Jaslo, where 3,700 tons (27,00 barrels) were obtained

Germany.—There are a number of small oil-fields in German which produce a limited quantity of heavy petroleum. The bul of the production comes from the Celle district.

Hanover.—A very interesting occurrence of oil in associatio with salt masses in a complex structure of Mesozoic rocks, com pletely hidden beneath recent formation. Oil struck at shallov depths is heavy, gravity .940 (19° B.); at greater depths lighter oi is struck. Wells are drilled to 500 ft. and 1,500 ft., but operation are impeded by quantities of salt water. Wells are rarely of grea capacity, though often long lived, and flowing wells are rare, the largest having given 300 barrels in one day.

Drilling commenced in 1889, and production increased graduall to over 110,000 tons (800,000 barrels) in 1908, from which figure it gradually sank to 63,000 tons (450,000 barrels) in 1913. The industry is now controlled by the Deutsche Bank, and energetic steps were being taken in 1914 to push the production. The price of crude oil is very high (13 M. the 100 kg.).

At *Hänigsen-Obershagen* the production was 7,400 tons (53,000 barrels) in 1913.

In Lower Alsace a growing production from drilled wells has been obtained since 1880, principally at *Pechelbronn*, 9 miles north of Hagenau. The occurrence is connected with the great trough fault of the upper Rhine valley, the field being located near the northern end of the Vosges Mountains. Oil is found both in Tertiary and Mesozoic rocks, varies from .880-.900 gravity (29°-25° B.), and close on 1,800 wells have been drilled to depths up to 1,300 ft. The estimated total production in 1913 was 140,000 metric tons. Previous to commencement of drilling, the asphaltic sand had been mined since 1742, the increase of depth revealing the oliferous origin of the asphalt.

India.—*Burma.*—The oil-fields of Upper Burma have steadily acquired increasing importance, and achieved fame by the great profits earned in recent years by the leading operating company. For many years the restricted production was drawn from shallow wells at *Yenangyaung* and *Yenangyat*, some 300-350 miles north of Rangoon, on the Irrawaddy River. Deeper drilling in the Yenangyaung field, by an enterprising operator, disclosed the existence of much richer sands than had been hitherto suspected, and the industry quickly leapt into considerable prominence.

Yenangyaung is being actively exploited by a number of competing interests, which have acquired well sites of small area from hereditary native owners. Wells are sunk within a few feet of each other, and much competition is displayed in the race for deeper new sources. The upper sands are becoming commercially exhausted, and deeper drilling is annually undertaken in the search for new sands. Wells are now drilled to a depth of nearly 3,000 ft. The southern section of the field, known as Beme, has proved disappointing.

The *Singu* field is located on the southern section of a range of hills flanked by the Irrawaddy. Below 2,000 ft. rich oil sands have been penetrated and worked along a distance of 2 miles, near the crest of an anticline running nearly north and south.

An oil-field which will one day attract activity is the Yenangyat, which follows the western banks of the Irrawaddy for about 20 miles, and has then been proved at intervals for 12 miles further northward. Only a few plots have been methodically operated, but the light density of the oil will certainly eventually lead to its active development.

At *Minbu*, 20 miles south of Yenangyaung, an oil-field has been worked with some measure of success, and in the Chindwin, 150 miles north of Yenangyaung, a field has been proved, and steps are being taken to transport oil to a convenient point on the river.

Numerous districts in Burma show promise, and the delay in prospecting may be chiefly attributed to their distance from the river, the main artery and medium of transport of the country. The production of Burma in 1904 was 440,000 tons (3,300,000 barrels), and in 1914, 1,100,000 tons (8,250,000 barrels).

Until 1908 all oil was transported from the oil-fields to the efineries at Rangoon by barges on the river; two barges, each of about 500 tons (3,700 barrels) capacity, being towed by a tug boat. The Burma Oil Company now conveys its oil by a pipe line from Singu and Yenangyaung to Rangoon, a distance of 275 miles. There is a small refinery at Yenangyat, from whence the Upper Burma trade is fed, but the main refineries are on the river near Rangoon, where there is sufficient depth of water for tankers of arge capacity to approach for loading.

Assam.—The frequency of oil indications in Assam had been he subject of comment and even investigation for nearly forty ears before active prospecting was undertaken by the Assam Oil Company. Pronounced indications of oil are said to be pread over an extensive area in eastern Bengal, Assam, and n the neighbourhood of Chittagong, where certain indecisive prospecting has been carried out. It is likely that many avourable structures will be eventually disclosed in the large number of parallel ranges of hills that traverse this little examined listrict.

Assam oil is derived from strata of Tertiary age on anticlinal olds in the north-east of the province, where it is usually associated with coal, also worked to some extent. The Assam Oil Company's works are at *Digboi*, some 60 miles distant from Debrugarh, on the Brahmaputra River. Wells sunk in disturbed trata yield for a time good supplies of paraffin-bearing oil, but the drilling difficulties are great, and the productions have been insufficiently sustained to enable the company to make very ubstantial profits. A refinery has been erected at *Debrugarh*, from whence the various produced products are distributed along the Brahmaputra River. Assam produced in 1898 about 2,200 tons (16,000 barrels), and in 1913 the production was 18,000 ons (133,900 barrels).

Japan.—The existence of oil has been long known, but only in 1865 were serious endeavours made to develop the fields which exist in Yesso and the northern part of Hondo. Early attempts ended in failure, and success first attended the efforts of the Nippon Oil Company, founded in 1886, who introduced the American cable system. At first numerous small producers came

into existence, but gradually these were absorbed by the Nippon and the Hoden Oil Companies, the former taking over the International Oil Company, an offshoot of the Standard, in 1907. The oil-fields of Formosa became of importance in 1905, when drilling was performed in fifty-three districts, but wells were short-lived. Now the two big companies have entered that island, the Nippon Company at *Konaisha*, in the southern part of the island, the Hoden with good results at *Byoritsu*, in the north. Formosa now produces half the home consumption.[1]

Recently the Nippon Oil Company has introduced the rotary method of drilling with marked success at *Kurokawa*, in the prefecture of Akita, where, on 25th May 1914, at a depth of 1,368 ft., a well was brought in at 480,000 gals. per day, but was capped, and at the end of the year was giving 1,700 tons. Another well, drilled in on 1st September, gave 5,500 barrels. The company is laying a pipe line 9 miles to the port.

The production in the first half of 1914 was 130,000 tons.

The Nippon Oil Company has three refineries at Kashiwazaki, Naoyetsu (formerly the International), and Niitsu respectively, and owns nearly 100 miles of pipe lines.

The Hoden Oil Company has absorbed 140 different companies, and possesses 1,500 wells. It has six refineries, treating 17,000 barrels crude oil per month at its largest in Kashiwazaki, the crude coming from Nishiyama. Other refineries are at Nagaoka, Niitsu, Nuttari, Nagaoka (No. 5), and Sekiya.

Central America.—Mexico is the only Central American State in which important oil-fields have been developed. Honduras is reputed to afford numerous and extensive indications of petroleum on the Caribbean coast line. Oil is said to exist in the Republic of Panama near the Costa Rica frontier, and seepages have been reported from Nicaragua and Guatemala.

Mexico.—Mexico has rapidly risen in importance as an oil producer. Although this is mainly due to the development of two areas, each with a few phenomenal producers, viz., *Potrero del Llano* and *Juan Casiano*, many other areas are definitely proved

[1] *Petroleum*, 1st April 1914.

capable of large production, and it may now be said that from Vera Cruz to Tampico is practically one oil-field.

In 1911 Mexico rose from seventh to third place in international importance, and in 1913 produced over 25,000,000 barrels (3,500,000 tons). In 1907 the production was estimated at 1,000,000 barrels (140,000 tons). *The Oil and Gas Journal* estimates the 1914 production as follows:—

	Barrels.	Tons.
Southern Fields (Tuxpam district)	18,830,359	2,690,000
Topila	398,679	59,000
Panuco	5,058,870	720,000
Miscellaneous (including Chila-Salinas and Ebano-Chijol)	1,118,995	159,000
Isthmus of Tehuantepec	328,500	45,000
	25,735,403	3,673,000

Mexican progress dates from 1904, when on the *Ebano* field a well was brought in which was still flowing in 1915. From 3rd April 1904 to 12th April 1912 it produced 3,450,123 barrels (500,000 tons), and at the latter date was giving 300-1,000 barrels (45-150 tons) daily. In 1905 the Pearson interests discovered the *San Cristobal* field, whilst on 4th July 1908 they struck the famous Dos Bocas well, the whole output of which was lost by fire. In 1909 the *Juan Casiano* field was proved by the Doheny interests, where one well, No. 11, has produced over 27,000,000 barrels (3,850,000 tons). 1910 saw the *Potrero del Llano* field proved, where No. 4 well has produced 25,000,000 barrels (3,500,000 tons), a large part of which was lost by fire and otherwise. In the neighbourhood of Tampico, in addition to the Ebano field, very important developments have taken place at *Panuco*, *Topila*, and *Chila-Salinas*. The Isthmian fields have not so far produced large quantities, and many causes have hindered the development of Tabasco and Chiapas, where indications are favourable.

The oil of the northern fields is usually essentially a fuel oil. On the isthmus of Tehuantepec, and in small quantities in the north, higher grade oils have been obtained.

The handling of Mexican oil is being gradually simplified and cheapened by the construction of pipe lines, as is the development of the fields by railways. From Potrero del Llano an 8-in. line runs to Tuxpam Bar (33 miles), at which spot the Furbero oil is shipped by submarine pipe line to vessels at anchor. From Potrero also a 6-in. line passes through other fields and delivers to Tampico, *via* the Tamiahua Lagoon, across which the oil is shipped in barges. Eight-in. lines connect Tanhuijo with Tampico, and San Diego to Los Naranjos.

From Juan Casiano a treble 8-in. line connects with Tampico (65 miles), whilst a double 8-in. line is laid to Cerro Azul (22 miles), an 18-mile branch taking in Tres Hermanos. The Southern Pacific interests have an 8-in. line from Panuco-Topila to Tampico, and from the Chila-Salinas field an 8-in. line connects to the Panuco River. From Furbero a 6-in. line 53 miles long connects to Tuxpam, and from El Alamo (the Pennsylvanian Mexican Company) 28 miles of 8-in. line are constructed to the same port. Altogether in 1914 there were 425 miles of 8-in. line in operation in Mexico, and 50 more in construction. Pearson's have a narrow gauge (24 in.) railway from Cuesillos on the Tancochin River to Los Naranjos, 12 miles in length, with one from La Pena to Potrero del Llano of the same gauge, 25 miles long. The Huasteca Petroleum Company owns 30 miles of 36-in. gauge railway from San Geronima to Cerro Azul, which is to be extended another 23 miles. The Pennsylvanian Mexican Company has 14 miles of narrow gauge line from Zapatal on the Tuxpam River to El Alamo, and the Oil-Fields of Mexico Company have 45 miles of 24-in. line from Furbero to Cobos on the Tuxpam River.

The main refineries are at Tampico and Minatitlan, but much oil is exported without treatment.

West Indies.—Trinidad alone has so far given proof of the existence of payable oil-fields, but indications of oil occur in Barbados and Hayti, and there are somewhat important deposits of asphalt in Cuba, said to be associated with oil. Asphalt has been obtained off the coast of Tobago.

Trinidad.—This island is fulfilling the anticipations of those closely allied with its pioneer work. Detailed geological investigations and exploratory drilling have confirmed the early impressions

of the author that the La Brea district would develop the most prolific oil-fields. Many wells from 700-2,000 ft. in this part of the island have yielded productions of from 5,000 tons (37,000 barrels) to 50,000 tons (375,000 barrels) within one to three years, and sufficient area is now proved to justify operations on a scale that would ensure a large and sustained export.

The development of the island has been impeded by scarcity of roads in the oil districts, and absence of transport facilities, whilst the health problem gave grave cause for anxiety until the forests were cleared and drained, and mosquito-proof buildings were erected.

Manifestations of petroleum on a phenomenal scale are to be observed at many points in the southern half of the island, and especially along the crests of anticlinal folds, often sharply inflected, which cross the island from west to east. At some six localities on these parallel anticlines commercial productions of oil have been proved by operating concerns within 6 miles' radius of the Pitch Lake. The oil of this district varies in density from .900-.970 (25°-14° B.), and is essentially a fuel oil.

Near *Tabaquite* a sharply folded anticline has been successfully developed, where oils of a density of .790 (47° B.), yielding 70 per cent. of benzine and lamp oils, are obtained at a depth of only 400 ft. At *Guayaguayare* and *Palo Seco*, on the main southern anticline, oils of light density have been struck in fair quantities, at moderate depths, and many seepages of light oil bear visual testimony to the wide distribution of high grade oils. The seepage at Lizard Spring, inland from Mayaro Beach, is probably one of the most important light oil issues ever recorded, gas and oil issuing in considerable quantities from numerous fissures in the strata.

Trinidad oils of the heavy type are now largely exported for fluxing asphaltic road mixtures, and to some extent treated for the production of "reduced" oils for road application. The residue of the dense oils forms an ideal road dressing, and is largely employed on the public roads of the island.

Oils of light density like Tabaquite, Guayaguayare, and Barrackpore yield high grade refined products, the former yielding in a local distillery about 40 per cent. of high grade petrol of .730

(62° B.) gravity, and a lamp oil which can be burnt in ordinary lamps without refining.

Barbados.—In the Scotland district of Barbados there are numerous and unmistakable indications of oil amidst the disturbed Tertiary strata that protrude from beneath the coral limestone in the district. A small production was at one time obtained near Turner's Hall by an operating company, and a refinery located on the seashore, 3 miles north of Bridgetown, produced distillates that found a local sale. The petroleum was of an asphaltic base, not rich in light oils, but very suitable for the production of lubricants.

The island has for a century exported a heavy oxidised oil under the designation of "Barbados tar," and a native bitumen, "Manjak," another product of oil, has been worked for many years. A considerable quantity of oil collects in the manjak workings.

Coral covers the island, with the exception of the central part which rises to an elevation of over 1,000 ft., but nowhere does the thickness of coral preclude the possibility of reaching the petroliferous sedimentary beds beneath, although drilling alone will divulge the structural features and degree of saturation with oil.

Dutch East Indies.—Oil-fields of immense value and great extent have been discovered and operated in the Dutch East Indian islands of Borneo, Sumatra, and Java, where extraordinary results have been achieved in a short space of time, whilst recently attention has been devoted to other islands, including Ceram, where a small production was recorded in 1913. The growth of the production for the whole Dutch East Indies may be gauged from the fact that in 1900 it amounted to 300,000 tons (2,200,000 barrels), whilst in 1914 it exceeded 1,600,000 tons (12,000,000 barrels). The oil is found in anticlinal folds with steeply dipping sides, and the axes are generally characterised by a wonderful display of the natural phenomena which are usually associated with petroleum. As in the other Eastern oil-fields, the oil-bearing strata are of Tertiary age, and are generally associated with coal and lignite. In Borneo there are both asphaltic and paraffin oils in the same oil-field at different depths. Some of the Sumatra oils are especially rich in light products, and these have been largely sought for the production of spirit for the European market.

It is asserted by prospectors in the East Indian islands that there are hundreds, if not thousands, of square miles of oil-bearing land which can be remuneratively exploited when occasion demands. Sumatra came to the fore as the original focus of activity of the Royal Dutch Company (Koninglijke Maatschappij tot Exploitatie van petroleum-bronnen in Ned.-Indie); Java was developed mainly by the Dordtsche Company; and the Shell Transport and Trading Company turned its attention to the east coast of Borneo. In 1905 the fusion of the Royal Dutch and Shell interests with the formation of the Bataafsche Company to control their joint oil-fields, and the subsequent absorption of the Dordtsche in 1911, already controlled for some years by the Royal Dutch, has resulted in the practical control of the whole Dutch East Indian oil-fields passing into the hands of this great combine.

Sumatra. — The pioneer of the oil industry in Sumatra was A. J. Zijlker, who obtained a concession of 500 bows (891 acres) in 1883 on the right bank of the Lepan River in the *Langkat* district, and energetically proceeding with its development, obtained a small gusher in 1885. He was supported by the Government, and meeting with considerable success, he managed to float the Royal Dutch Company in 1890, which, in the following year, built a light railway to Pangkalan Berandan, on the navigable stream Babalan, and erected a refinery on the Bay of Aroe, connecting this with the fields by pipe lines. In 1894 a loading port for large tankers was built on the island of Sembilan. Production made rapid progress, several gushers being struck, and the following year the area under concession was largely extended, proving the existence of an anticline 30 km. (19 miles) long between Boeloe Telang and Besitan, the main field being located at *Telaga Said.* Langkat oil has a sp. gr. of .771-.857 (52°-33° B.).

At first a rather conservative drilling policy was followed, it being thought that the production, obtained by drilling four wells annually, would suffice to fill the requirements of the refinery, the capacity of which was 80,000-100,000 tons (600,000-750,000 barrels) yearly, but owing to water troubles a rapid falling off in the production from 159,000 tons (1,200,000 barrels) in 1898 to 52,000 tons (390,000 barrels) in 1899, led to the adoption of a more vigorous policy, and drilling in other areas commenced.

The Perlak Oil Company started in 1901 and the South Perlak in 1905. Both companies, which own adjoining concessions in Atjeh, further north-west than the Langkat district, are now controlled by the Royal Dutch Company who pipe the oil to their refinery, a distance of 150 km. (94 miles). The production of the Perlak Company in 1909 was 286,000 tons (2,100,000 barrels), that of South Perlak Company 61,000 tons (460,000 barrels); but in 1914 the output had fallen to 135,000 tons (1,000,000 barrels) and 11,000 tons (82,000 barrels) respectively.

The south-eastern end of the Boeloe-Telang-Besitan anticline has been worked for many years by the Shanghai-Langkat Company (Maatschappij tot Mijn-Bosch- en Landbouwexploitatie in Langkat). This company came under the control of the Royal Dutch in 1909. Its production in 1914 was still about 300 tons (2,200 barrels) a day.

As long ago as 1897 in southern Sumatra, the Moeara Enim Company and the Sumatra-Palembang Company were formed, which developed with considerable success structures of a type similar to those known in the northern end of the island.

The principal areas producing are at *Kampong Minjak* and *Moeara Enim*, whilst Meliamoen, Babat, and Liaman Loeloei have all yielded considerable quantities in the past. In 1901 the Moesi Ilir Company was formed to exploit a large concession near Babat, but now all three companies are controlled by the Royal Dutch. The oil is high grade; that at Meliamoen has a specific gravity of .765-.775 (53°-51° B.), at Kampong Minjak .792 (46.5° B.), and at Babat .812-.889 (43°-27.5° B.). The fields are connected by pipe lines to the refineries at Pladjoe and Bagoes Koening, both near Palembang.

North-west of this district lies a most promising area known as *Djambi*, which was put up for auction by the Government in 1911-12. It is understood that the area will be divided between the Royal Dutch and the South Perlak Companies. In North Sumatra drilling was proceeding in 1914 at Peudawa.

Java.—The oil industry of Java is in the hands of the Dordtsche Company and its subsidiaries, which until 1911 had a marketing agreement with the Royal Dutch, but is now absorbed by that company. The company was formed in 1887 and

developed rapidly, the production in 1913 exceeding 200,000 tons (1,450,000 barrels). The occurrence of oil in Java is widely disseminated, but owing to the geology of the southern and western part of the island being complicated by igneous intrusions, the fields which have hitherto yielded the production are located in the north-east corner of the island, in the provinces of Semarang, Rembang, Soerabaja, and the island of Madoera, which forms the eastern continuation of this part of the island. In Rembang the chief production comes from *Tinawoen* and *Panolan*, whilst in Soerabaja the principal pools are at *Twalf Dessas*, *Lida Koelon*, and *Made*, all of which have been steady producers for years. The depths of wells in Java are not great, usually 500-800 ft., the most productive horizon occurring at the junction of the Middle and Upper Miocene. The oil is heavier than that from Sumatra, its specific gravity ranging between .825 and .916 (40°-23° B.). It has primarily an asphaltic base, yet yields a paraffin of very high melting point. Two refinery centres have been established, one at Wonokromo treating the oil from the Soerabaja fields, the other at Tjepoe in Rembang for the western fields in Rembang and Semarang.

Borneo.—Attempts to work oil on the east coast of Borneo were made as far back as 1863 by J. H. Menten, who obtained a concession, "Louise," in 1888 at *Sanga-Sanga*, in Koetei. This still remains the main productive area. Drilling began in 1897, oil being struck at 190 ft. A second concession to the south of this, at *Balik Papan*, was acquired in 1891, and the two passed into the hands of the "Nederlandsch-Indische Industrie- en Handels Maatschappij," affiliated to the Shell Company in 1898, which company erected a refinery at the excellent harbour of Balik Papan, the oil being shipped in lighters from Sanga-Sanga. About the same time the Koetei Exploration Company was formed, which eventually passed into the hands of the Royal Dutch. Prior to the formation of the combine the East Borneo Company, closely related to the Royal Dutch, had acquired three productive concessions at Sanga-Sanga, Tapang, and Anggana in 1903, whilst the Shell interests had secured a third concession, "Nonny," in 1900.

In North Borneo numerous seepages are known, and for many

years efforts have been made to develop the fields which are believed to exist in British North Borneo, Brunei, with the adjacent island of Labuan, and Sarawak. So far, with the exception of *Sarawak*, where a production of 65,000 tons (470,000 barrels) was obtained in 1914, no very definite results have been obtained. In 1914 drilling was proceeding at Sibetik, on the east coast of British Borneo. Between this point and the original fields on the east coast lies the island of *Tarakan*, at the mouth of the River Sibawang, which has developed into a very important producer, the production amounting to 258,000 tons (1,850,000 barrels) in 1914.

Borneo oils are similar to Baku oils, and are treated in like manner. The shallow sands in the Koetei fields yield heavy oil, with paraffin, which has a gravity of .970 (14° B.). The lighter oil from deeper sources has a specific gravity of .860-.890 (33°-27° B.), and is poor in paraffin.

Persia.—The rich Persian oil-fields have been developed, as yet, only in their more accessible portions. At Maidan-i-Naphthun some thirty wells have been completed, but production has not been at full capacity, no wells having been yet pumped. In twelve months, ending March 1912, the production was 82,000 tons (600,000 barrels), and in the subsequent six months 138,000 tons (1,000,000 barrels). The field is connected with the refinery at Abadan by a pipe line 145 miles long, part of which is 6 in. and the rest 8 in., with a daily capacity of 1,000 tons (7,200 barrels).

The refinery was started in 1913, and is designed to remove 30 per cent. of the lighter products, leaving 65 per cent. as residues to be used as Admiralty fuel oil. It has a throughput per battery of four stills of 7,500 tons (55,000 barrels) monthly which yield 4,800 tons (35,000 barrels) of fuel oil. Thus the total capacity of twenty stills is 24,000 tons (175,000 barrels) per month, an amount in excess of the carrying capacity of the pipe line.

The kerosene derived from Persian oil is destined to supply all Persia, except in the immediate vicinity of the Caspian Sea, where Russian kerosene will continue to compete successfully. The home demand (some 30,000 tons—225,000 barrels annually) will, however, form but a small market for its disposal.

One well is said to have yielded by flowing over 100,000

tons of oil, and if this is any indication of the possibilities of the area, the Persian fields are destined to become very important.

Canada.—Although indications of petroleum have been reported from many parts of Canada, no fields have been operated to any important extent except those of Ontario, where the oil appears to be confined to sandstones and limestones of Palæozoic age. The producing fields of Ontario are chiefly located in *Lambton Co.*, and the township of *Petrolia* is the centre of the petroleum interests. Many of the wells in the Petrolia district do not exceed a depth of 500 ft., and their cost is often below £100, as the limestones in which the oil is found are very easy to drill. In some other districts, as Tilbury, the wells are deeper, and they cost a much larger sum to complete.

The Ontario oil is usually of the paraffin class, and is rich in illuminating products, but it contains an excessive amount of sulphur, which imparts to it an offensive odour. The wells do not often yield more than twenty-five barrels monthly, after sometimes a primary spurt, and often only five barrels a month after many years.

Alberta, British Columbia, and Athabasca have all disclosed evidences of petroleum worthy of closer investigation by the Canadian Geological Department. Large areas in the *Medicine Hat* and *Bow Island* districts of Alberta have proved to be exceedingly prolific of natural gas at depths of 1,000, 1,300, and 2,000 ft. respectively, and already schemes have been considered for the conveyance of this valuable fuel to Winnipeg and other large industrial centres. Calgary and other towns are already supplied with natural gas, but the demand is insignificant when considered in connection with the enormous supplies available.

Great local excitement was aroused in 1914 by the striking of a small production of high grade oil in a well 30 miles from *Calgary*. Lands for hundreds of miles around acquired unheard of values, and speculators were induced to subscribe large sums on prospects of the wildest type. That the district justifies methodical prospecting is true, but the structures are intricate and the folds sharp, confining probable fields to strictly narrow limits.

The tar sands of *Athabasca* have long been considered a

possible source of petroleum if penetrated under suitable stratigraphical conditions that might be disclosed by careful study. Western Canada will doubtless receive more attention in the near future, as there are many districts on the eastern flanks of the Rockies presenting favourable indications and structures.

The output of the Ontario field has diminished since 1899, when it attained about 108,000 tons (808,000 barrels). Natural gas is still profitably worked and regularly supplied to a number of towns in Ontario.

Several serious efforts have been made to develop an oil-field in New Brunswick, where indications of petroleum are pronounced. Numerous wells have been sunk to depths of 2,000 ft., and high grade oil has been struck, but hitherto the quantities have not justified more extended operations. Natural gas has been struck in considerable volume and converted to useful employment, and the shales around the Alberta mine have been the object of repeated investigation with a view to their treatment.

Africa.—Except in Egypt, no oil-field of importance has been brought to light, and elsewhere Algiers alone has furnished real encouragement. Both the Ivory Coast and Gold Coast have been tested in the region of the Tano River with little success, and in Nigeria, where financial assistance was given to a prospecting company by the Government, no results were attained to justify the somewhat extravagant anticipations. In Angola and in Madagascar investigations have been conducted, and in the latter island drilling has been performed so far with insignificant, if not negative, results.

South Africa has been searched fairly well by prospectors, with little encouragement, although there are indications of oil and gas at many spots. In 1914 the British Government was induced to investigate certain indications of oil in Somaliland.

Egypt.—At two places on the coast of the Gulf of Suez commercial supplies of petroleum have been struck, and development on an important scale has been undertaken. The oil from the *Jemsa* and *Hurgada* fields is conveyed to Suez, where a large refinery has been erected for its treatment. Some wells gave large initial flows under high pressure, and there is every prospect of important

oil-fields being developed when the geological conditions are better understood.

During 1913 the production at Jemsa amounted to 12,000 tons, but early in 1914 a big gusher was struck, raising the production to over 1,000 tons daily. Successful drilling was also carried out at Hurgada. The Egyptian production for 1914 was 103,000 tons.

Indications of petroleum have been observed on certain islands in the Red Sea, but drilling on an extended scale has yet failed to locate commercial bodies of oil.

Algeria.—Petroleum has been won in small quantities from an oil-field situated near the port of Oran, where wells sunk to a depth of 1,400 ft. have given small but persistent yields enabling a small refinery to be intermittently worked. The fields lie along the southern flank of the Dahra range, between the River Chelif and the sea; the age of the rocks most commonly associated with the oil is Cretaceous and Tertiary, but the actual source of the oil has not been elucidated.

South America.—Of all the great South American States which severed their connection with Spain and Portugal, Peru alone has developed, up till 1914, any oil-fields of importance. This is the more strange, as several countries present attractive features in the way of indications of oil, or profitable and protected markets. In the *Argentine Republic* a field was accidentally discovered when drilling for water, and this may provide the clue to other discoveries in the country.

Asphalt deposits of commercial value have long been known and worked on a remunerative and commercial scale near the mouth of the *River Orinoco*, and are evidently associated geologically with the asphalt and petroleum deposits of the neighbouring island of Trinidad. Geological investigations have been made on an extensive scale, and large sums have been expended on drilling, with inconclusive results. Productions of oil were obtained but its excessive density gave it little value, except for certain and quite restricted uses.

On the borders of Lake Maracaibo prospecting operations have resulted in proof of the existence of petroleum, and it is said indications warrant optimistic views. Other parts of Venezuela have been the object of investigation, but difficulties of title

inaccessibility, etc., have prevented *bona-fide* operators from attacking the problem.

The coastal belt of *Colombia*, from the River Magdalena to the Atrato, has been the scene of repeated geological studies and some serious drilling operations, but with indifferent and certainly indecisive results. Oil indications are very pronounced in some localities, and sufficiently encouraging yields of oil and gas have been obtained to stimulate further efforts.

Ecuador can boast of promising signs of oil in an exceedingly favourable geographical position at St Helena, near the delta of the Guayaquil River. A small local oil industry flourishes in the district through the extraction of oil from shallow pits, sunk into outcropping oil sands. The strata are evidently a continuation of the Peruvian belt, and are worthy of more attention than has hitherto been bestowed on them.

A strip of land along the eastern flanks of the Andes in *Bolivia*, from Yacuiba to Santa Cruz, presents frequent indications of oil, where beds of a certain known age reach or approach the surface under suitable structural conditions. Inaccessibility and labour difficulties have doubtless contributed to the little attention attracted by the deposits.

Even from *British Guiana* pitch deposits are reported, although in somewhat difficult and remote territory, and natural gas has been struck during drilling in the Essequibo delta.

Peru.—Peru can boast of one of the finest oil-fields in the world. Along a coastal belt of Tertiary rocks extending from near Tumbez on the northern frontier, to Payta a little south of Point Parinas, there are numerous manifestations of petroleum, and at least three important oil-fields have been exposed and are being actively exploited.

At *Negritos*, *Lobitos*, and *Zorritos* important oil-fields are being actively and profitably operated. The joint production in 1914 was about 300,000 tons (2,200,000 barrels), and extensive exports of benzine were being made.

Ten years previously the production of Peru did not exceed 50,000 tons (375,000 barrels) per annum. The wells of Peru vary in depth from 300-3,000 ft., and they have a long life, ultimate yields of from 3,000-5,000 tons (22,000-37,000 barrels) per well being common.

Favoured by a healthy climate, the tropical heat tempered by perennial cool southern breezes, the absence of rain and desert-like surroundings impose no hardships, and enable work to proceed in a way unknown in any other oil country. Drilling is easy and rapid, no water difficulties occur, and the light density oils are much sought after for the extraction of petrol.

There is a well-equipped refinery at the Port of Talara, where various products are prepared, cased, and shipped to the west coast markets from Chile to California. There is also a small refinery at Zorritos. Fuel oil is largely used by the railways of Peru, by some of the steamships on the coast, and by the Nitrate Oficinas of Chile.

Petroleum has been found at *Punta Rustin*, between Lobitos and Zorritos, and also near *Lake Titicaca*, where fair yields of paraffin-bearing oils have been struck.

Italy.—Three small oil-fields have been developed in Italy, and indications of oil are spread over a very wide area. The Montichino property, Emilia oil-field of Lombardy in the valley of the Po, has proved profitable to work under a high protective duty, and another region in the Pescara and Lins Valleys, Central Italy, has been the scene of a small industry.

Australasia.—It is curious that no oil-field of importance has yet been located in these great British possessions. Promising indications of oil have been reported in New Guinea, and other manifestations have been repeatedly described from Kangaroo Island and the neighbouring mainland of South Australia. At Roma, west of Brisbane, a fierce expulsion of natural gas from a deep well opens up possibilities that should not be disregarded by the authorities. The New South Wales shale deposits, upon which such great sums of money have been lost, may one day be of great value. A small oil-field has been developed at Taranaki, near New Plymouth, in the North Island, but extended drilling amidst indications of oil elsewhere, have so far failed to expose appreciable supplies of petroleum.

CHAPTER II.

CUSTOMS, LEASING, AND VALUATION OF OIL-FIELDS.

Commercial Aspects of Petroleum—Leasing of Oil Lands—Royalties and Consideration in Leases—Obligations in Leases—Valuation of Oil Properties, Lands, and Royalties—Oil-Field Waste and its Prevention.

Commercial Aspect of Petroleum.—A study of statistical data does not necessarily convey the true capacity of oil-fields, as normal development is often influenced by strictly local considerations, which adversely or favourably affect operations. Most oil-fields rely mainly upon some defined markets, but restricted dependence naturally diminishes with proximity to seaboard. The discovery of a new prolific oil-field or a richer deeper source in an old field may for a time demoralise prices and call for a complete re-adjustment of conditions. Old fields or small producing wells may have to be abandoned as unprofitable until a demand is created in, or transport facilities afforded to, new channels for the surplus production.

Few products are subject to more severe fluctuations of price than petroleum, and no product has probably in turn entailed on operators greater hardships and yielded larger rewards. Within ten years the price of oil in Baku fluctuated between 7s. and 47s. per ton (22.4 cents and $1.50 per barrel), a difference of nearly 700 per cent., and in many of the newer oil-fields of America the price has varied from 10s. to 30s. per ton (32 cents to 96 cents per barrel), 300 per cent. within a few months. Over-production in Galicia (in the sense of insufficient transport facilities) in 1908 caused the price of crude oil to relapse to 6s. 6d. per ton (20.8 cents per barrel), but in 1913 it had risen again to nearly 80s. per ton ($2.56 per barrel), a difference of over 1,200 per cent.

The unavoidable fluctuations in price of petroleum are well illustrated by reference to the Baku oil-fields, where, in one month, a single well has yielded 400,000 tons (3,000,000 barrels) of oil,

equal to the entire annual output of many large oil-fields where thousands of wells have been sunk and hundreds of thousands of pounds spent to secure the same yield.

Violent fluctuations of prices become less prevalent with the increasing magnitude of the industry. The greater the field, the more facilities for removal and distribution over a wider area are in existence. In large centres financiers are usually found willing to buy and store or finance surplus stocks of oil instead of allowing them to be thrown on the market. The balancing effect of powerful competing interests was well illustrated in Roumania in 1912-13, when a well of a company with practically no storage or export facilities yielded within sixteen months 400,000 tons (3,000,000 barrels) of oil without depressing the high prices prevailing at the time.

In 1913 the active development of the prolific and easily worked Cushing field in Oklahoma led to a fall of prices from \$1.05 to 75 cents per barrel, equal to 28.6 per cent. within a few weeks. As the difference between 75 cents and \$1.05 per barrel represented that extra profit to the operator, the full extent of the reduction of profits will be appreciated.

Petroleum yields such a variety of products of quite different and changing values that efforts to secure additional supplies of one product may be the cause of throwing surplus quantities of other less valuable products on the market, that quickly neutralise the anticipated profits. At one period in Russia up to 1870 lamp oil was the aim of refiners, benzine was burnt as fuel, and the residuum destroyed by burning. A few years later residuum was the object for which all worked, and its price was frequently little below that of all other products. Still more recently benzine, illuminating oil, gas oil, and fuel oil were all largely sought, each participating in yielding a good aggregate price.

Until about 1900 benzine, the most profitable of all products of crude oil, was deliberately burnt, either as fuel or for disposal in many of the great oil-fields.

As the main use of most oil products is as fuel, there is some general relationship in price to other combustibles. Residual fuel oils compete directly with coal, peat, wood, or other fuel, and a particular market often exhibits an expansion or contraction in

inverse relationship to the price of oil. As the chief oil-fields of Russia are located around the Caspian Sea, with the Volga system of water transport as its natural outlet, an increased price of fuel oil causes the encroachment of coal and wood on the oil fuel area; a reduction in price of oil fuel creates an immediate expansion of its markets into the coal and wood areas.

With other oil products it is much the same. Internal combustion engines are encouraged if fuel is cheap, and displaced by gas engines, suction gas plants, or steam if the price of oil rises. The capital cost, per horse power, of different classes of power is well known, and the working costs depend practically entirely upon the cost of oil. There is, consequently, a limit when prices act adversely upon the oil markets, and distributors carefully estimate whether a highly profitable but curtailed sale is to be preferred to a less remunerative but increased trade. When there is a scarcity of transport, those favoured with means of conveyance are in a position to exact a maximum price from the public, although there may be, in some fields, immense supplies of the desired product in stock, and the producers on the verge of ruin, owing to the absence of buyers at remunerative prices. With a normal transport charge of about £2 per ton, there were, in 1914, huge stocks of benzine suffering high evaporation losses, and awaiting a purchaser in Oklahoma, at a price of about 6 cents per imperial gallon (£4 per ton), when the selling price in Great Britain, less tax of 3d. per gallon, was 1s. 4d. per gallon, or about £20 a ton.

At the same time California was suffering severely from excessive freights and shortage of transport facilities, substantial profits only being made by those companies operating in the rich areas, where flush productions reduced the cost of production to a nominal figure.

The fact that petroleum mining is as speculative as other classes of mining is often overlooked. True, its extraction and preparation for market are much simpler and cheaper than most metallic ores, but its development is attended with equal risks, and it is always the drill and the drill alone that definitely decides the value of oil properties, precisely as bore holes and shafts do in metalliferous or coal mining. Whatever the wealth

of indications, and however confident the prospector, the risks must be realised till the capabilities of the oil sands have been given a practical test.

The occasional booms and extravagant speculation in oil lands are no more excusable than gold rushes such as have been witnessed in Australia, California, and Alaska. Regrettable as they are, such events will never be avoided so long as petroleum yields such great rewards to the successful. Whilst human nature endures, discretion and prudence will be periodically cast to the winds by speculators in a scramble for unknown stakes. Nor does it seem reasonable to preach caution when fortunate operators can be seen drawing an income of £1,000 to £5,000 ($4,800 to $24,000) a day from a well which has cost them but say £2,000 to £5,000 ($9,600 to $24,000) to drill.

A single Russian well in 1908 gave within one month oil to the value of £270,000 ($1,300,000). Had that same well been struck in 1914, the value of the oil would have been £1,200,000 ($5,760,000), or £40,000 ($192,000) a day. The Columbia well on the Moreni field of Roumania in 1912-13 gave oil valued at £1,200,000 ($5,760,000) within eighteen months, high prices synchronising with a wonderful natural flow. This well was not the property of a rich company, but a comparatively small concern, which had for years been struggling against adversity.

A few fortunate strikes of oil in Mexico have sufficed to pay dividends on capital running into millions sterling, thus compensating for years of unremunerative exploitation under almost the worst possible political and labour conditions. Valued at £1 per ton (60 cents per barrel) at the well, the output of individual wells in Mexico has been maintained for months at figures which would represent £10,000 to £15,000 ($48,000 to $72,000) a day. Many an oil-field operator has been suddenly raised from a state of almost destitution to affluence by the strike of a rich well.

On the collapse of the rubber boom in 1910, speculators sought a new object of attack, and the selection fell upon oil. Stimulated by a Press campaign emphasising the scarcity of oil products, and exaggerating the requirements of the British Admiralty and other naval Powers, who were projecting the use of oil fuel, popular interest was stirred. Money was freely

subscribed by the public for world-wide ventures, often with inflated capitalisations and insufficient working capital. Dead and forgotten properties were resuscitated and window-dressed with remarkable audacity, with the natural result that many concerns quickly came to grief, thereby throwing discredit upon an industry displaying exceptional potentialities. A competitive demand for proved or partially developed oil properties naturally led to excessive requests by vendors, and numerous subsequent reconstructions and liquidations bore testimony to the errors that those closely allied with the industry deplored.

Unprecedented excitement was, in 1914, aroused in Western Canada, where a small strike of light oil led to a quite unjustified speculation in lands for hundreds of miles around Calgary. Scores of companies with fanciful names and inflated capitals were promoted, and the shares were readily disposed of to credulous persons notwithstanding official warnings.

It would be well to dispel the fallacy which has been obtrusively circulated that oil-field development requires much more money than other commercial enterprises. The cost of equipping an average oil property bears no relationship to that required for a mine of the same tonnage; indeed, the development of an oil property that lies within the sphere of railways and roads is often well within the means of a private well-to-do citizen. The prospecting and opening up of unexplored tropical forests is a much bigger task, that should only be entertained under skilled and experienced guidance.

There are thousands of small operators in the American oil-fields who have started with little, and built up substantial and respected businesses, and wherever there is a free market for crude oil, there are excellent prospects for energetic, enterprising men with knowledge of the industry and of business capacity. The oil industry in most countries has been established and built up by numerous small operators, who have subsequently often been induced by tempting offers to sell their interests to financial groups, after amassing a good bank balance. It has, in fact, been the small man who has laid the foundation of oil enterprise in all but a few countries, where the conditions of living and disposal of products were prohibitive.

The failure of so many public oil companies is due to causes unconnected with the value of the properties acquired, and the abilities of those in charge. Over-capitalisation is frequent, but this by itself is open to adjustment, and scarcely figures. Almost the sole source of trouble in many cases is scarcity of working capital. The prospectus appears to provide for all contingencies, but the trouble arises from the almost universal phrase, "Working Capital and General Purposes of the Company," the latter part of the phrase covering a wide field, and usually monopolising a large part of the available funds. It is often wonderful what a mass of legal matter has to be cleared up before real work can be commenced, and what a host of claimants appear for compensation. Then there is often an adjustment of stocks from some date, and purchase of these and sundry plant, not included in the sale, at a valuation. It is surprising what value insignificant items acquire at such times.

A prolific source of unexpected expense is often the transfer of the acquired properties, sometimes aggravated by a series of undisclosed lawsuits of old standing, the new tenants being considered fair game for being less acquainted with the facts, and more ignorant of the laws and customs of the country than their predecessors.

Oil companies thus often start off with their working capital depleted to a dangerous degree before serious work is commenced, and a few misfortunes, due possibly to the change of management and withholding of essential information, may cause work to be suspended, or loans to be contracted, at very early stages of their career. Weak underwriters often fail to meet their commitments when success is not assured, and this may prove a deciding blow.

One of the most serious and often overlooked matters in the promotion of oil companies is the money required for financing the business. Cash is rarely transferred on a sale, and a period has to be provided for between the extraction and sale of oil, or receipt of proceeds of sale. Stocks of material have to be carried to avoid long and expensive stoppages on the properties, and this involves the locking up of large sums.

Stocks of oil can sometimes be financed, and accounts may be paid by the proceeds of discounted bills, but there are times when

stocks cannot be financed, and bills can only be discounted at a prohibitive rate.

Companies often allow themselves to be involved in business for which no financial provision had been made. New lands may be purchased with obligations to drill, causing double financial embarrassment if funds run short through failure of some preconceived programme, or disorganisation of the work through a fire or other cause. It is, indeed, rarely that expenditure is not incurred in some direction not originally anticipated, thus modifying all original calculations of requirements.

An analysis of the accounts of a number of oil companies shows how disproportionate is the expenditure on drilling to that on unremunerative work. Published balance sheets rarely disclose sufficient data to arrive at this figure, but it is obvious that it is drilling alone which will secure, maintain, or increase production. Tankage and pipe line provision for contingencies that never arise are a fruitful object of needless expenditure and diversion of funds, urgently required for the operation which alone will yield the material to transport and fill the tanks.

Another serious difficulty, which has not been without important influence on the success of prospecting companies, is the labour problem. The phenomenally rapid progress of a comparatively new industry has led to a great scarcity of men trained or experienced in the work. The employment of half-trained or inexperienced men in any industry is an expensive business, yet all but long established oil companies have had to combat with this unavoidable but serious defect. Capable, qualified engineers could not be easily tempted to leave warm posts in good climates to settle in unexplored regions, and risk permanent loss of health, however large the remuneration offered. In initial tropical development the author has at times had to face cases where 70 per cent. of the staff and labour were incapacitated by fever at one time. Given health even, the troubles connected with the training of unskilled labour in some new fields of operation are very trying and disheartening.

However, apart from all other considerations, the petroleum engineers can hardly fail to be despondent when they are called upon to direct new companies with an issued capitalisation of

say £250,000 ($1,200,000), providing only some £50,000 ($240,000) working capital. This, again, may be cut down by a "general purposes" clause to perhaps £40,000 ($192,000), which modest sum has to justify the capitalisation of £250,000. An industry has to be wonderfully remunerative to withstand such watering of capital. Far more oil companies have failed from financial mismanagement than failure of the land to respond to operations or technical control, mainly in consequence of diversion or misdirection of funds. Few investors in mining prospects complain about the loss of their money if spent in honest endeavours to develop promising territory, but all object to waste of money through improvidence or deflection from the objects for which it was provided.

Many interesting compromises and arrangements have been made by governments and public bodies at the instigation of producers and refiners during periods of depression in the oil industry; conditions created and encouraged by those seeking relief. Anticipated results have rarely been achieved by interference in the normal developments of trade, and further complications have often ensued. Few oil-fields of importance have escaped periods of acute depression where unrestricted development has been in force, and those times of low prices have often been the direct means of advertising areas, attracting capital, and securing for products outlets which would otherwise never have been established.

Operators in America have hitherto failed to induce legislative bodies to draft ordinances which would restrict development, and thereby assist financial interests in rich fields. In some cases something very near compulsion has been introduced by the formation of local bodies, who have assumed authority which could never be legally enforced. Oklahoma producers have acquiesced in the demands of certain self-constituted bodies, rather than risk a conflict with unauthorised but influential powers that could cause much trouble and inflict petty annoyances.

Californian producers sought to maintain the price of oil by forming bodies called the "Independent Producers' Agency" at various oil centres. Those joining the agency undertook for a number of years to sell all their oil through the agency, and accept

a certain amount on account for such oil as should be placed in storage pending sales at a fixed minimum. This agency eventually controlled an immense output, and to some extent assisted in arresting the declining tendency of prices, by restricting the operations of members. The agency exercised its power to make large sale contracts by an agreement with the Union Oil Company of California, and also built pipe lines.

At one time many Grosny producers united to fix a minimum selling price of 10 copecks per pood (12s. 6d. per ton, 42 cents per barrel). But a few who declined to join the combination caused much embarrassment by undercutting, and forced the combine to place large supplies of oil for a time in stock.

The great power possessed by the pipe line companies, upon whom the smaller operators often exclusively rely for the disposal of their products, has led to a general demand for the isolation and State control of such public utility concerns. They exercise a powerful influence over the areas they tap that could easily be interpreted as abuse of privileges at times. Oklahoma pipe line companies in 1914 decided to accept only 50 per cent. of the settled production of properties during the period of overproduction in that State, following the developments at Cushing.

Galicia afforded an interesting example of attempts to defeat depression in 1911, when the output of the famous Boryslaw-Tustanowice oil-field had quite outgrown its usual markets. As an example of the extent to which operators are willing to relinquish their position at moments of difficulty, the case is especially instructive. When crude oil prices were low, refiners made large profits at the expense of the producers, but when the price of crude oil rose the profits of refiners were seriously diminished. When struggling producers induced the authorities to erect large storage for surplus crude oil, and to make advances on oil put into storage, the price and output of crude oil rose rapidly, and refiners were working at a loss. Burdened by a tax of £6. 8s. per ton ($4.09 per barrel) on illuminating oil, home markets were restricted in view of the agreement of refiners to maintain a fixed price for home sales.

Surplus oils were thrown on the German market at any price they would fetch, thus rousing the antagonism of the Standard

Oil Company, who promptly retaliated by undercutting the Austrian home market. So fierce became competition that negotiations for an agreement were opened.

The Austrian Government was led to intervene and purchase 1,500,000 tons of fuel oil for the railways at a price of nearly 24s. per ton (77 cents per barrel), but this caused but temporary relief, and crude oil prices fell to 5s. per ton (16 cents per barrel), at which moment the Standard Oil Company offered to expend £250,000 on storage tanks of a capacity of 1,000,000 tons. They tendered an advance on stored oil, but demanded the exclusive right of light distillates obtained in the preparation of fuel oil. Negotiations were cut short by the intervention of the Austrian Government, who realised what the producers were parting with, and they themselves decided to install storage on a large scale, and purchase more fuel oil. The immediate result was a leap in the price of crude oil from 6s. 8d. to 29s. per ton, 20.8 cents to 92.8 cents per barrel, and once more refiners found themselves unable to fight the aggressive attacks of the Standard Oil Company when the stocks of cheap oil became exhausted. The Austrian Government was subsequently led to introduce legislation of such a far-reaching character that the Standard Oil Company were practically compelled to close down their refineries in Austria, a situation which diplomatic representations failed to remedy.

Endeavours to make an equitable allocation of tank cars to Baku refineries before the pipe line to Batoum was built, and when facilities for export were quite inadequate to deal with production, led to interesting results. On advice of a committee the Russian Government was induced to allocate tank wagons in proportion to the actual quantity of oil treated in the refineries. This regulation placed a heavy burden on small refiners, who were often compelled to work at a loss, in order to secure the necessary wagons for disposal of a reasonable part of their products. Eventually the acute crisis arising from temporary over-production, in conjunction with restricted export facilities to Batoum, led the Government to grant a rebate of 11 copecks per pood on export oil conveyed to Batoum. Its object of relief to small refiners was defeated by the excessive demand for tank cars with delivery at Batoum at a specified date, the result being a keen speculation

that placed a premium on tank cars about equal to the sum conceded.

Consideration for the peasants led the Roumanian Government in 1908 to pass legislation authorising the annual allotment to the various refineries of the country of a fixed proportion of the internal consumption of kerosene, the price of which was not to exceed a predetermined amount that afforded a reasonable profit to refiners. For the purpose of the Bill the refineries were divided into three classes thus :—

1. Large refineries with throughput capacity exceeding 40,000 tons per annum.
2. Medium refineries with throughput capacity between 40,000 and 10,000 tons per annum.
3. Small refineries with throughput capacity under 10,000 tons per annum.

The distribution was on the basis of annual throughput capacity, but the law differentiated in favour of the small refiner, who could not work so cheaply as the large refineries, by granting to the second class 200 per cent., and to the third class 400 per cent. more than the first. The ratio is therefore 1 : 3 : 5. In one year, when the home consumption was estimated to be 42,000 tons, or 1.6 per cent. of the throughput capacity, the distribution of the internal trade was as under, the refineries in practice only treating about half their throughput capacities.

	Throughput Capacity of Refineries.	Allotment.
1st category	1,886,000 tons × 1 × 1.6 per cent.	30,176 tons.
2nd category	115,800 tons × 3 × 1.6 per cent.	5,558 tons.
3rd category	78,000 tons × 5 × 1.6 per cent.	6,240 tons.

The internal consumption was taken at 42,000 tons = 1.6 per cent. of 1,886,000 + 347,400 + 390,000 = 1.6 per cent. of 2,623,400.

There were eight refineries in the first, five in the second, and forty-two in the third group.

The price was such that at normal times good profits were secured to refiners, but there have been times when this usually sought for right in reality imposed a burden, if not an actual loss, on refiners.

Germany in recent years was seriously considering the formation of a Government petroleum monopoly, which no doubt would have proved a very lucrative source of revenue. Russia imposes

an excise tax on illuminating oil (kerosene) of 60 copecks per pood (77s. per ton, $2.46 per barrel), and derives a revenue which reaches a very large figure.

A great deal of ignorance has been displayed in discussions concerning the general displacement of coal by oil. Until the available supplies of coal show a great diminution or the cost of mining increases considerably, oil can never compete with coal in most of the seaports of the world. It is only in a few isolated spots at periods of over-production that fuel oil will be obtainable at 30s. a ton ($1 per barrel), which is necessary to compete with bunkering coal at 20s. a ton. Quite apart from the cost of fuel the total oil supply of the world in 1913 only amounted to about 50,000,000 tons, compared with a minimum output of 1,000,000,000 tons of coal, that is, it constituted only about 5 per cent., of which amount less than half could be rendered available as fuel in boilers.

Leasing of Oil Lands.—It was the practice for many years in most countries to apply the standard mining regulations to petroleum, and the confusion and absurdities thus occasioned may be imagined. Official attempts to dispose of essentially oil problems on ordinary mining lines led to interesting and instructive legislation in the case of the Trinidad pitch lands, where endeavours were made to allocate the quantity that was reasonably due to each of the many little plot owners in the La Brea district.

Only in recent years has the leasing of oil lands been admitted to the application of special regulations, framed to meet exigencies that never occur in metal mining. The public dangers and irretrievable losses arising from unrestricted oil-field operations compelled authorities to formulate stringent, though not aggressive legislation, to regulate the conduct of lessees of both private and public oil lands.

No fixed regulations can be drawn up and applied indiscriminately to a number of oil-fields. Most oil-fields of the world present characteristic features demanding quite different handling. A selected and acceptable unit of area in one field would be absurd in another field, and mild restrictions in one area would inflict irritating hindrances in another.

Legislation connected with the leasing of public lands lies in

the direction of (*a*) fixing a minimum area which shall constitute a separate lease; (*b*) imposing a rate of royalty, and the form it shall take; (*c*) stipulating minimum drilling obligations, or alternatively, minimum annual payments; (*d*) insisting on fulfilment of certain reasonable conditions to safeguard the property from improper or injurious treatment or wasteful development.

The unit of area of public lands varies greatly from an acre or two to a square mile. It is determined by the richness and number of oil sources; this, in turn, reflecting upon the number of wells and distance apart.

Difficulties are at once apparent in endeavours to override the sacred liberties of private ownership, but what limitations are imposed create indirectly a minimum area, by such means as regulating the distance of wells from boundaries, dwellings, boiler house, etc., thus automatically rendering plots of small area as separate units valueless. Negligent or unskilful development of a single plot may imperil a whole field by admitting unexcluded water to the oil sands. Likewise improvident proprietors may endanger hundreds of wells by failure to adopt precautions against fire or suitable oil control devices. In the United States, where oil lands are generally privately held, local regulations or accepted customs eventually solve the difficulty, although serious abuses have been witnessed at rich areas like Spindle Top, Texas, where single well locations were bought and sold by speculators with deplorable results, which it is hoped will not be repeated. The general adoption of the 10 dessiatine—27 acre—unit in Russia, based originally on Baku practice, has been a great hindrance to the normal development of other less rich fields in that country, and is a proof of the fallacy of standardising a unit of area for a country.

Lands in the United States are divided into ranges, townships (36 sq. miles), and sections (1 sq. mile), all square blocks, so that a separate lease, only in exceptional circumstances, is less than 40 acres, $\frac{1}{16}$ of a square mile, the minimum area of land grant. The land subdivisions in the United States apply only to the west and middle west, the older States having been settled before the scheme was evolved. Hence in Pennsylvania, etc., irregular holdings are the rule. Certain oil-fields extend within the

boundaries of villages and towns, like Oil City and other Pennsylvanian towns, and Los Angeles, where wells are sunk in the gardens of houses by arrangement with the proprietors. Californian oil leases frequently consist of units, or groups of 1 sq. mile units, although in rich centres subdivision has led to an area of 40 acres being common.

Public oil lands in the various States of the Union have, in the past, been acquired under placer law, and are, with the exception of Texas, under the control of the Federal Government. Large areas of land were alienated for agricultural purposes before their oil value was known, and these constitute the bulk of the numerous properties so extensively worked in the country. Naval requirements, need for conservation of oil and gas lands, and the high value such lands have assumed, led the Washington Government in 1910 to withdraw all known oil and gas lands from public location, with the intention of formulating suitable laws and regulations for future disposal.

Lands acquired within petroleum reserves under placer law prior to 1910 are valid so long as the stipulated obligations are fulfilled, but the conditions of holding are known to be unsuitable to fluids. It was realised that under the provisions of placer law powerful corporations could, at inconsiderable expense, obtain control of large areas, and retain them by some pretence of work: Means were also found to secure valuable oil land under the subterfuge of other minerals, entailing far less expenditure to fulfil the requirements of discovery.

The Federal Government granted to the various States of the Union at the time of their incorporation a certain amount of land, the proceeds of which were to be applied to the support of schools and State institutions, but in this area was not to be included lands known to contain minerals. In many cases State lands have been found to be underlain by oil, and thus the States themselves have become possessed of territory which they are entitled to lease on such terms as they may decide.

California and Nevada have interpreted the original intention of the Federal Government to retain all mineralised ground, and have through their legislatures disclaimed title to such lands, thus allowing them to revert to the application of Federal laws. Texas,

which controls its own mineral lands by the terms of its incorporation in the Union, has restricted sales of oil and gas lands to 640 acres, except in certain cases when 1,280 acres may be taken.

Several of the States have fixed the maximum area of oil and gas land to be acquired by a single person or corporation at 640 acres, and in the Indian (Choctaw, Chickasaw, Cherokee, Creek, and Seminole) reserves of Oklahoma a maximum of 4,800 acres has been wisely insisted upon. Osage lands are leased in blocks of between 320 and 5,120 acres, and all Indian leases are subject to the approval of the Federal Government, as protectors of the Indians.

An attempt was made in 1915 by powerful interests to force the hands of the authorities in the case of the 4,800 acres limit law of the Indian territory above referred to. Offers were made to construct pipe lines into new territory if larger grants of land were made to the promoters of the scheme, it being claimed that such small acreages did not justify the capitalists expending the large sums the projects involved. Even ordinary small producers were induced to support such demands in the hope of finding a quick outlet from lands held.

Land tenure in the United States is surrounded by some difficult problems, arising from the withdrawal of public lands from mineral location, settlement, selection, filing, and entry under mineral public land laws. The President has exercised his authority under the Act of 25th June 1910 to withdraw all known oil and gas lands in the States of California, Wyoming, and elsewhere from public location to form a petroleum reserve, and a number of cases awarded in favour of location owner in local courts are under appeal, and in partial abeyance pending reconsideration of the laws at Washington.

Litigation of great importance, involving enormous stakes, is pending between the Southern Pacific Railway Company and the U.S. Government. The Government endeavours to secure cancellation of certain patents, alleged to have been improperly obtained by the railway company in 1904-5 under the Act of 1866—lands subsequently ascertained to have high values for oil. Other vast areas acquired under patents, particularly excepting all mineral lands except iron and coal, are the subject

of dispute, it being affirmed that patents were procured by false representations, and knowledge of the occurrence of petroleum and other minerals. The oil lands are largely held by the Associated Oil Company, the holding subsidiary of the Southern Pacific Railway Company, and their extent and value is immense.

In Roumania and Galicia oil lands are mainly held by the peasants. As agricultural countries, the great landlords acquired the rich plains, magnanimously leaving to the peasants the assumed valueless hilly districts where the oil-fields are almost exclusively located. Customs of heredity have led to the subdivision of property into narrow strips, as each proprietor in turn, on his decease, divided up the property amongst his children. Estates miles long and a few yards wide are common, and without amalgamation it is often difficult to select a well site that will fulfil the Government regulations.

An independent oil property in Galicia must have a minimum area of 12,000 sq. metres (about 2 acres), and a width of at least 60 metres.

A feature which seriously impeded the natural development of proved oil-fields in some countries was the question of title. The rightful owner was difficult to discover, or he carefully concealed his identity till his relations and friends had been generously rewarded as supposed owners, and serious work was well in hand. The rightful heir appeared in due course, and indignantly demanded the removal of plant, unless extortionate compensation were paid. So scandalous became this practice of extortion in Roumania, that the Government was induced to protect would-be operators by a Bill called the Consolidation Law, empowering a court of law to hear evidence of title, and decide upon the merits of various claimants. Registration of title in this court after adjustment of all disputes established good title, and no wise operator dreams of working on peasant lands without the land being consolidated.

The mineral rights are alone leased as a rule in Roumania, the peasants retaining the right of occupying the surface, where it does not interfere with the oil-field work. Twenty-nine years is a usual term of lease, and the conditions are either a royalty, rent, or both, or lump-sum payment.

Prolonged and involved litigation arising out of land tenure

on conquered territory has for years effectively delayed the development of many oil areas in Russia, where rival claims of the peasants and the Government cannot be adjusted. Owners of land in the vicinity of the Baku oil-field were forced to prove the validity of their titles, but this did not empower the Government to suspend working on disputed leases, as they would, in the meantime, have become valueless by activity on adjoining lands. Some litigation continued for many years, during which period millions of tons of oil were extracted and sold. The Russian Government eventually won the cases, and much curiosity was aroused as to the means they intended to adopt to recover their royalty. Tenants were, however, treated with consideration, and they were allowed to continue in occupation on payment of a moderate lump sum in compensation for oil extracted.

In undeveloped or partially developed British possessions like Burma, Trinidad, and Egypt, there has long been a disposition to grant first short-termed exploration licences for conducting a flying survey and geological examination, followed by a prospecting licence granting greater facilities over less extended areas, with definite obligations for a certain period within which a development lease must be applied for over some prearranged maximum proportion of the prospecting licence. Under such conditions the square mile unit is convenient and adopted, but authorities would be well advised to retain alternate plots or groups of plots until the true worth of the area has been conclusively demonstrated by fairly extensive operations.

Petroleum leases rarely convey other rights than power to occupy the necessary land for the operations of drilling for petroleum or gas, and compensation on a liberal scale is often provided for damage sustained by buildings, trees, cultivation, etc. The title deeds of land in some countries specially reserve to the Government all mineral rights, and the authorities are empowered to grant mining leases on such terms as they may determine, although provision is usually made for suitably compensating disturbed owners of surface rights.

In South American Republics, where the Spanish mining laws are left almost intact, petroleum, though not specifically included, is treated under the same category as some other minerals, and

prospecting rights, or *pertinencias*, may be secured by payment of a nominal sum to the nearest official of the mining department. A full mining lease over certain selected areas may be subsequently obtained by a declaration of discovery (denouncement), and the payment of larger fees and an annual rental. In *Peru* the annual charge for a pertinencia of 4 ha. (say 10 acres) is 30 soles (£3).

Venezuela allows a unit of 1 ha., and demands an annual rental of 1 bolivar (10d.), as well as a royalty of 1 bolivar per ton of oil produced. In the *Argentine* the exploration licence covers 500 ha., but in open lands up to 2,000 ha. may be acquired in one block; with one unit 140 days are allowed for exploration, each further unit adding 50 days. Pertinencias are 18 ha. in the case of fuels. For some years the Government has endeavoured to develop some of the better known areas, the lands being withdrawn from the public.

In *Bolivia* an oil lease in newly discovered districts had a maximum area of 64 ha., entailing semi-annual payments of certain dues; but this is temporarily in abeyance, a law having decreed that for five years, from the 1st January 1912, no fees are to be paid.

In *Mexico* the law of 1883 placed the ownership of oil deposits with the landlord. This was one of the factors which enabled the industry to go ahead, as large areas were obtained on easy terms at the wild-catting stage, the reverse holding good now in developed areas. In July 1912 the Government introduced a tax of 20 centavos (5d.) per ton on all oil produced.

Columbia has much the same law as Mexico.

Russia presents a variety of interesting problems in connection with land tenure and oil rights, especially in the conquered provinces of the Caucasus, where the great oil-fields are located. Prospecting licences (*zayafki*) are granted in unproved territory for one to two years at a rental of 5 roubles per dessiatine (say 3s. 7d. per acre) on units of 37½ dessiatines (about 100 acres), from which 10 dessiatines (27 acres) can be selected, and a lease called an *otvod* taken out if oil be found. Evidence of research and discovery must be given before an *otvod* will be granted, but compliance with the law is usually met by digging three shafts to about 30 or 40 ft. As soon as a district has been declared oil-bearing, only development leases (*otvods*) will be granted.

The minimum unit of area permitted under Russian law for an oil property is one dessiatine (2.7 acres).

A curious and unique custom prevails in the Yenangyaung oil-field of Upper Burma, where certain native well owners, Twinzas, possess ancient and hereditary rights, recognised by the Government, over well sites inscribed by a circle 60 ft. in diameter (.065 of an acre). Hand-dug shafts were sunk into shallow oil sands, and a peasant industry long flourished, but the proved existence of rich deeper sands, which mechanical drilling alone could reach, led to keen competition for their acquisition by operating companies, and in consequence, much congestion of wells on the 200 acres composing the field.

Realising the value of an oil strike on an estate, it is not unusual for an enterprising proprietor to offer a bonus of free oil rights over a certain acreage to a prospector who will undertake to sink a few trial wells in likely territory.

Royalties and Consideration in Leases.—Royalties are payable in kind or in value, either as a fixed percentage or on a predetermined quantity or valuation per unit of volume or weight. It is curious that volume, which is a variable factor dependent upon temperature, should have become accepted in some countries as the unit of calculation.

Many interesting problems arise from the consideration of royalties. Payments in kind are obviously inconvenient in most cases, and are only acceptable by Governments, public bodies, or the few lessors requiring petroleum for some purpose. Its period of free storage and the losses sustained by such storage often entail disputes, but there is the advantage that, whatever the state of the market, the lessors obtain the full benefit. Percentage royalties payable in cash are open to the difficulty of amicably fixing a price of crude oil, no simple matter when there are no regular dealings or accredited oil exchanges. Operating companies naturally object to the contents of their books being disclosed, and if the lessee both produces and refines, and it is required that the value of the crude oil shall be calculated from the selling prices of a dozen products, in as many or more markets, confusion reigns supreme, especially under the skilful and mysterious work of book-keeping.

A fixed cash sum per unit of measurement involves no intricate

calculations, and the main objection lies in the burdens it is supposed to impose at periods of low prices, and the excessive profits it credits to producers at times of prosperity. This form of royalty constitutes a simple, clean transaction which makes it popular.

Russia has provided instructive examples of Government endeavours to pacify indignant producers by readjustments of royalties at periods of extreme depression and great prosperity. Original nominal rentals were unquestionably too lenient, and were subsequently replaced by a fixed sum per unit of weight. Definite sums per unit of weight were the object of vigorous protests from producers when prices were low, and by those not holding lands when prices were high. The Government was alternately charged with intentions of ruining the industry and with unfairly supporting a few favoured ones according as prices fell or rose, and at times sufficient pressure was brought to bear on the authorities to cause them to modify the terms of royalty. As is commonly the case, the producers themselves were the first to regret their agitation, as it almost invariably acted against their interests in due course.

Sometimes leases are subject to reduced royalties with increased outputs, with the object of stimulating development, but in Russia these terms were fiercely assailed at periods of over-production and low prices, whilst popularly demanded at times of more restricted output to prevent the locking up of Government oil lands.

Throughout the United States the prevailing royalty varies from one-tenth to one-sixth, and where exceptionally rich land has been disclosed by drilling, premiums are demanded on the basis of fixed sums per acre, a much more satisfactory plan than imposing royalties that will at no distant date burden the industry to an extent which renders exploitation unprofitable.

In the State of Texas a fixed minimum charge is made of \$15 an acre on oil and gas lands situated within 10 miles of a railway, and \$10 an acre on lands more distant; but prospecting is allowed for one year free of the above charge. Colorado demands a royalty on State lands, the amount being fixed by Land Commissioners. In Wyoming, State lands supposed to contain oil are leased for five years, with obligations to perform work, at an

annual rental of $16 per acre, and a royalty of 10 per cent. of gross production of oil. New Mexico imposes a minimum rental of $25 per quarter section (160 acres), and a minimum royalty of 5 per cent. on gross production for five years only.

Oklahoma grants oil and gas exploitation rights to the highest responsible bidder at public auctions. The period is five years, and no offer of less than 12½ per cent. is entertained. Indian reserve lands are leased for oil on a basis of a 15 cents to 70 cents per acre rental, merging into a royalty of not less than 12½ per cent. for a period of ten years. For gas wells an annual royalty of $100 is payable, or $50 if used only for private purposes.

Lands allotted to Indians outside the reserves may be leased for twenty years subject to permission of the Commissioner of Indian affairs. Royalties may be revised at five year intervals, and a bond of $1,000 is demanded. Osage tribal lands in Oklahoma are offered by auction, approved by the Secretary of the Interior. A rental of 15 cents, 30 cents, 50 cents, and $1.00 is demanded for the first four years, and $1 per acre per annum afterwards, merging into royalties of 16⅔ per cent. on gross production based on market value of the oil, on not less than a guaranteed minimum of 60 cents per barrel. Gas sold is subject to 16⅔ per cent. of actual value realised.

Unproven lands are frequently leased on a 10 per cent. basis, with no onerous obligation to drill unless oil is struck in the locality. Canadian farmers of Ontario have often derived a welcome supplementary income by a 10 per cent. royalty on oil or gas extracted without hindrance to agricultural pursuits. A fixed annual charge of from 25 cents to 50 cents per acre is charged on oil and gas lands in Manitoba, Saskatchewan, North-West Territory, and Yukon, the lease being for a period of twenty-one years subject to renewal on certain terms. British Columbia imposes a rental of 15 cents per acre for five years, with a royalty of 2½ cents per barrel on all oil extracted, but vigorous and continuous development work is specified. A bounty of 1½ cents per imperial gallon (17s. per ton) is paid by the Canadian Government on all crude oils produced or put in storage in Canada.

When the existence of oil has been virtually proved by neighbouring operations, royalties are often increased somewhat, and

substantial bonuses demanded in addition, the latter varying from 4s. ($1) to as much as £30 or £40 ($150 or $200) per acre. Favourably located Illinois oil lands in 1907 were frequently acquired at a premium of £30 ($150) per acre, in addition to one-eighth royalty: £5 ($25) per acre is quite a common bonus.

In 1915 the sinking of a single gas well of 50,000,000 cub. ft. a day capacity, near Corpus Christi in South-West Texas, led to many thousands of acres of land being taken up by producers and speculators in the county of San Patricio. Owners of land demanded and obtained premiums of $5 to $50 per acre and 20 per cent. royalty, and even short options were sold for $2 to $35 per acre.

Proprietors of oil and gas lands frequently stipulate in their leases that they are entitled to as much gas as they require for their personal, domestic, and farm purposes.

An interesting and unusual practice flourishes in Roumania, whereby peasants sometimes receive an agreed sum per productive well or hand pit sunk. These amounts vary from 500-600 francs per well. The customary practice in Moreni is to demand a fixed royalty of 10 per cent. in cash, the price being generally based on the prevailing official quotation for the quality of crude oil extracted. Remuneration in other districts is generally less.

Galician royalties average about 14 per cent. in the rich fields, and a regular trading in royalties is conducted. Royalties are subdivided into single percentages, or even fractions of 1 per cent., and there is a market valuation which constantly fluctuates with the prospects of the property or well on which the royalty is held. These royalties are payable in kind, and the credit notes find a free market and authorise holders to take delivery of the quantity of oil they represent.

Royalties in Russia vary according to the administration under which they fall. In the Baku oil-fields, the original 27-acre leases were granted for a payment of 10 roubles per dessiatine (7s. 5d. per acre) for the first ten years, 100 roubles per dessiatine for the next ten years, the rental being multiplied by ten at each ten-year period.

A curious situation arose in 1913, following the offer by the Russian Government of a number of oil-bearing plots of land in the

TABLE II.—TERMS OF LEASING OF RUSSIAN GOVERNMENT OIL LANDS.

Name of District in which the Plot is Located.	Number of Plot.	Area of Plot.		Depth in Sazhen necessary to be Drilled and Time Allowed from Date of Contract.		Period of Lease.	Amount of Deposit to be Furnished.		Minimum Annual Production on which Payment is to be made to the Government of the Difference between Market Price and Agreed Price for the Period.				Amount of Annual Diminution of Minimum Production in each Succeeding Year Compared to the Previous Year, for the Period from Jan. 1923 to the end of the Lease.	Royalty on Market Price on all Production above Minimum.	Amount of Crown Oil which Lessee is bound to Store in his Metal Tanks together with his Own.
		Dessiatine.	Square Sazhen.				At Auction.	On Allotment.	From 1st Jan. 1915 to end of 1915.	From 1st Jan. 1916 to end of 1916.	From 1st Jan. 1917 to end of 1917.	From Jan. 1918 to end of 1923.			
				Sazhens.	Years.	Years.	Roubles.		Thousands of Poods.				Quantity in Poods.	Per Cent.	Quantity in Poods.
							½		¼	½	¾	1			
Romany -	17 R.	1	2,156	300	2½	30	12,000	24,000	150	300	450	600	30,000	25	12,000
Saboontchy -	7 S.	4	818	700	2½	30	30,000	60,000	375	750	1,125	1,500	75,000	25	30,000
Balakhani -	5 B.	5	1,200	450	2½	20	6,000	12,000	75	150	225	300	30,000	10	6,000
Binagadi -	16 Bn.	8	1,080	450	2½	20	4,000	8,000	50	100	150	200	20,000	10	4,000
Romany Lake	31 R.	4	471	750	2½	30	32,000	64,000	400	800	1,200	1,600	80,000	25	32,000
Bibi Eibat -	18 B.E.	8	2,323	900	2½	30	50,000	100,000	625	1,250	1,875	2,500	125,000	25	50,000

Sazhen = 7 feet. Dessiatine = 2.7 acres.

Rouble = 2s. = 50 cents. Pood = 62.2 lbs.

Baku oil-fields of Russia, under somewhat novel and unprecedented conditions, doubtless designed to reconcile conflicting views. The tabulated statement is abstracted from the full list of lands offered, and is representative of those offered in the six areas enumerated.

Leases were for a period of twenty to thirty years, and besides a stipulated minimum amount of drilling, there was a payment on an obligatory minimum annual production that attained its maximum in nine years. Presumably with the idea of stimulating development, the Government requested offers on the basis of a cost of production, the difference between the market price of oil and the tendered cost of production as the minimum being payable to the Government; consequently, in the event of a true cost of production being proferred, the lessee would derive no profit from the minimum production, but take all his profits from any surplus of production subjected to a straight 20-25 per cent. royalty.

Keen competition arose for the good plots, with the curious result that not only were many petitions put in with a cost of production put at nil, but actually minus costs up to as high as −47 copecks per pood; that is, not only would lessees pay to the Government the whole of the value of the minimum obligatory production, but 47 copecks per pood also. With oil at 30 copecks per pood, the Government would be paid 77 copecks per pood on the stipulated minimum, and lessees would rely upon the profits of surplus oil subjected to 20-25 per cent. royalty to pay them, as well as refund the difference of 47 copecks plus their cost of production. The Government rightly rejected all tenders, and withdrew the lands, as it was quite clear that such offers were not made by *bona-fide* operators intent upon normal development, but by speculators or operators desirous of protecting neighbouring properties. Both would eventually have to bear unsupportable burdens before the thirty years expired, and a fall of prices to a low level would have entailed losses at any time that even the richest firms would have found embarrassing.

On other occasions Government lands put up to auction were secured at from 25-75 per cent. royalty: the higher bids were made either to secure lands to protect existing properties, or to wastefully exploit by drilling to fountain sources, and abandoning the property when the flush production was abstracted, unless the authorities re-

considered the royalty. When advertised for auction on the basis of a fixed sum per unit of weight, amounts fluctuating between 1 copeck per pood (1s. 4d. per ton) and 12 copecks (15s. 9d. per ton) were bid, the figure differing greatly, as would be expected, with the state of the market.

Much could be written on the earnest endeavours of the Government to afford *bona-fide* producers opportunities to acquire reserve oil lands, and the way these efforts were frustrated by the clever devices of speculators.

Cossack lands in Russia are subject to an annual rental of 25 roubles per dessiatine (20s. per acre) and 1 copeck per pood (1s. 4d. per ton) royalty on oil produced up to 1,000,000 poods (16,000 tons), and ½ copeck per pood (8d. per ton) on larger quantities. The lease is for a period of twenty-four years, but the Cossack Administration has the right to impose new royalty conditions at the end of twelve years if continued possession is desired. Some leases in the best territory in Grosny field, which came up for consideration in this way, were subsequently renewed on percentage terms acceptable to the lessees.

The Burma royalty is 8 annas per 100 viss (5s. per ton) to the Government, but intermediaries who acquired oil lands and transferred them to others, and Twinza proprietors often demand an additional 8 annas per barrel. Basing the value of oil at 5 rupees a barrel, the Government royalty is equivalent to 10 per cent. Double royalties, such as are exacted in many cases, are a serious burden on operators, in all but the exceptionally rich areas.

During the maximum productive period of the Yenangyaung field, by which is meant the time when the best yield was obtained per well, and the richest sources of moderate depth were being exploited, prices of £3,000 ($14,400) were paid for individual sites. This works out at a rate of about £46,000 ($220,000) per acre, and as a yield of about 20,000 tons (150,000 barrels) per well was at that time an optimistic estimate, this represented an additional charge of about 3s. per ton (9½ cents per barrel).

Royalties are generally payable on the net production of petroleum, by which is meant that all oil necessary for the working of the properties may be used free of royalty. Unless carefully guarded against, costly disputes may arise from this clause, as

claims have been made and upheld for oil lost by fires, soakage, and other causes not entirely attributable to neglect.

Interesting and useful discussions arose in Russia from the net production clause, which are worthy of close attention. When electrical power was introduced into the Baku oil-field by public power stations, lessees of oil lands complained that in paying the electric power companies for energy consumed they paid also for oil used as fuel, which, of course, released an equivalent amount of fuel oil on their properties subject to royalty. They consequently correctly argued that they were being penalised for introducing economies on their properties. The Government admitted the justice of the claim, and eventually made an acceptable allowance to lessees who purchased electric power from outside sources.

In Burma the Government imposed a tax on boilers burning oil on the oil-fields, for the purpose of revenue, and unintentionally effected an important inducement and praiseworthy incentive to utilise natural gas, which had hitherto been neglected for some unknown reason, although there was plenty available, and the system of working was particularly suitable for its collection. This idea is worthy of repetition in other fields, as an incentive to that economy which appeals so much to all engineers.

Petroleum royalties should be imposed on a graduated scale to ensure absolute fairness to landowners and operators, but this could only be undertaken when dealing with public authorities or large bodies. Farmers and small landowners cannot be expected to understand the intricacies of mining customs and laws, and they usually view with suspicion any suggestions based on uncertainties that they are quite unable to appreciate. The scientific treatment of royalties would have to be separately undertaken in each field, with knowledge of all local conditions, and include several variables, as the price of oil is such a fluctuating one and the cost of labour and materials a changing factor. It must be recalled that original long-period leases are usually made when oil is first discovered and when little or nothing is known regarding the potentialities of the field. A value is established by the law of supply and demand in the same way as the price of other commodities is fixed, but subsequent events may prove the market value to be inflated or under-estimated as it was not founded on any ascertainable basis.

The cost of developing an oil-field and the cost of extracting oil usually increase with the age of the field, in consequence of the diminished productions per well, and often necessary deeper drilling; consequently, other conditions remaining constant, the returns for a definite expenditure are reduced and the royalty constitutes the only factor that could be reduced to avoid all profit being eventually obliterated; but against the increased cost of operating there is often a rise in the price of oil that entirely or partially neutralises the reducing yield, at least for a time. If the cost of drilling wells and extracting oil remained fixed the equation

$$(\text{average production per well}) \times (\text{price of oil}) = \text{constant}$$

would represent a stationary state of affairs, but if working costs increase, the constant is displaced by a figure with an annual augmenting value. Applying the above formula to known oil-fields a value for the constant could be determined above or below which the local industry is in a flourishing or a depressed state.

Obligations in Leases.—Lessors of oil lands are rarely so careless or unbusinesslike as to lease their lands on a royalty basis without certain obligations, unless substantial bonuses or rentals are paid, which are regarded as ample compensation for inactivity. Both public authorities and private landowners have experienced the difficulties attending the fixing of definite obligations which impose no unfair burden on lessees. Private landowners may be divided into two classes—the cautious, thrifty ones, and those endowed with speculative instincts. The former prefer a definite rental, minimum annual royalty, or other fixed payment. The latter choose to throw in their lot with the lessees and rely upon production for their remuneration, consequently insisting upon drilling obligations within definite periods.

Public authorities have in view a dual purpose when drafting leases. They not only desire revenue, but they strive to create a local industry which in turn benefits the public exchequer in a variety of indirect ways, often more important than the revenue from royalties. Townships spring up, increasing the value of land, and attracting population to support the many trades which are automatically drawn by a thriving enterprise. The

introduction of great quantities of plant and machinery necessitates transport and repairs, and often refineries are the eventual outcome with their associated industries.

A minimum payment calculated as a royalty percentage from an assumed price of oil is frequently inserted in leases, and it is often a fluctuating amount increasing at stipulated intervals. Minimum royalties merge into percentage royalties, and are made to apply to each year separately. Sometimes development work is encouraged by decreasing the royalty with increments of production. Thus the first 10,000 tons in any one year might be subject to 10 per cent. royalty. The second 10,000 tons to 7.5 per cent., and subsequent production to 5 per cent.

The imposition of minimum working conditions is not the simple matter it appears at first sight when leasing new lands where no standard of work has become recognised. It is usual to aim at a definite amount of drilling per unit of area, and is arrived at by reasoning backwards from the following assumed or imperfectly appreciated data.

1. The number of wells per unit of area the land will support.
2. The life of the wells.
3. The number of sources of oil.
4. The time of drilling a well.
5. The average depth of wells.
6. The average production of wells.

One thus arrives at an approximate annual minimum footage per unit of area that will keep engaged a certain number of drilling rigs that should, with good fortune, attain and maintain a minimum output during the period of the lease granted.

In new territory a footage rate is often unfair, as the difficulties of drilling are unknown, and the author has always advocated in preference the maintenance in constant operation of at least one modern rig per fixed acreage, until a minimum production has been reached, suitable interpretations of this clause being inserted in the licence or lease.

Peasants and farmers have often been constrained to part with their oil rights in ignorance of their prospective value, or by misleading or seductive promises which enabled lessees to evade

work, and either speculate with the land or hold it up. In some of the United States oil-fields custom has superseded law, and the courts support applicants for relief upon moral and equitable grounds. A farmer who has disposed of his rights on a royalty basis may demand a well to be drilled to offset a producer near his boundary on an adjoining property. Failure of the lessee to comply with this reasonable request imperils his holding, as the proprietor may grant the right to others, and he can scarcely anticipate any compensation if he invokes litigation.

The Roumanian Government has construed agreements in much the same common-sense way, and by the "Ten Years' Law," which was passed in 1914, no oil leases may be held up and remain undeveloped for a period of ten years. If approved work is not conducted on peasant lands within the specified time, the agreements are automatically cancelled, and the rights revert to the landowner. Although the passage of the "Ten Years' Law" was deliberate, and its application intentionally directed against the leading operating groups who were securing control of large reserve areas in the country, with no immediate intention of seriously prospecting, there were some who opposed its principles on the score that it encouraged too rapid development. These opponents feared that a policy might be created whereby operations would be concentrated in newer fields, and large flush yields would so reduce prices of crude oil that the older and widely held fields could not be worked at a profit.

In formulating obligations reasonable provision should be made for reserve land. Whilst purely commercial considerations may dictate intensive but expensive and wasteful development of oil land, public opinion is becoming increasingly hostile to this class of work, and the cautious operator works methodically, and spaces his wells to secure the maximum depletion of the and with a minimum of cost, the period of extraction being thereby lengthened. It will be found increasingly difficult in the near future to endanger natural sources of mineral wealth by incautious work, and to allow thousands of millions of cubic feet of natural gas to go to waste merely to suit the convenience and pocket of an operator in search of some, for the time being, more marketable or more remunerative source underlying the

neglected sand. In leases of public lands clauses dealing with waste and approved workmanship are often incorporated.

Whilst a strong advocate of the conservation of natural resources and reasonable restrictions to safeguard public lands, the author would venture to issue a warning against undue interference in the details of property working. There is an inclination to multiply the restrictions to a needless and irritating extent, which only serves to arouse the antagonism of those in control.

Below is an example of a typical lease made by farmers in the Ontario oil-fields of Canada :—

THIS LEASE, made the day of A.D., between of , in the County of and Province of Ontario, farmer, hereinafter called the lessor, of the first part, and , hereinafter called the lessee, of the second part. In consideration of the agreements herein contained, the lessor does hereby grant and lease unto the lessee, for the term of five years, and so long thereafter as oil or gas is produced from the land leased in paying quantities, the exclusive right to drill for and produce petroleum and natural gas, and the right to conduct all operations necessary for the production, storage, and transportation of oil or natural gas, with the right to use water and gas (if found) for the necessary engines, and to remove all machinery, fixtures, etc., placed by the lessee on the premises, namely: , in the Township of , County of , Province of Ontario, being acres more or less. No wells to be drilled within feet of buildings without lessor's consent. The lessee to deliver to the lessor on the premises, free of cost, the one-tenth part of all petroleum produced and saved from the premises, and to pay one hundred dollars ($100) per annum for each gas well from which the gas is marketed for lighting any village, town, or city. If the lessor shall request it, the lessee shall bury all oil and gas lines below plough depth.

Lessee to pay compensation fo. any actual damage to crops or improvements caused by operations, to keep all gates closed and fences as found, and to pay all taxes rated on any property or effects he may place thereon.

This lease to be null and void and no longer binding on either party if operations for drilling are not commenced on the premises within days from this date, unless the lessee shall thereafter pay yearly to lessor twenty-five cents (25¢) per acre for delay.

It is understood between theparties to this agreement that all the conditions between the parties hereunto shall extend to their heirs, executors, administrators, and assigns.

Lessor to have free use of gas (if found) for household purposes on the premises during said terms.

SIGNED and sealed by

The following is an example of an oil and gas lease used in the Pennsylvanian oil-field :—

THIS INDENTURE, made the day of A.D. 19 between of the of County of and State of , lessor, and , lessee.

WITNESSETH, that the lessor, in consideration of dollars, the receipt whereof is hereby acknowledged, being rental in advance for months from the date hereof, does hereby grant, demise, and let unto the said lessee, all the oil, gas in and under the following described tract of land, with covenant for the lessee's quiet enjoyment of the term, and that lessor has the right to convey the premises to the said lessee; together with the exclusive right unto the lessee to operate and drill for petroleum and gas, to lay and maintain pipe lines, to erect and maintain telephone and telegraph lines, and buildings convenient for such operations; and the right to use water and gas from said lands in operating same, and right of way over same for any purpose, and right of ingress, egress, and regress for such purposes, and of removing, either during or at any time after the term hereof, any property or improvements placed or erected in or upon said land by said lessees, and the right of subdividing and releasing all or any part of all that tract of land situate in the of County of and State of , and bounded and described as follows, to wit:—

On the North by the lands of ;
on the East by the lands of ;
on the South by the lands of ;
on the West by the lands of ;
containing acres, more or less.

TO HAVE AND TO HOLD unto and for the use of the lessee for the term of years from the date hereof, and as much longer as oil or gas is produced in paying quantities, yielding to the lessor the one-eighth part of all the oil produced and saved from the premises, delivered free of expense into tanks or pipe lines to the lessor's credit.

Should a well be found producing gas only, then the lessor shall be paid for each such gas well at the rate of dollars for each year, so long as the gas is sold therefrom, payable quarterly while so marketed.

Lessee agrees to complete a well on said premises within months from the date hereof, or pay the lessor dollars each three months in advance from the day of until said well is completed or this lease surrendered. And the drilling of such well, productive or otherwise, shall be full consideration to lessor for grant hereby made to lessee with exclusive right to drill one or more additional wells on the premises during the term of this lease. Lessor is to fully use and enjoy said premises for the purpose of tillage, except such parts as may be used by lessee for the purpose aforesaid. Lessee is not to put down any well on the lands hereby leased within ten rods of the buildings now on the said premises without the consent of the lessor in writing. Lessor may, if any well or wells on said premises produce sufficient gas, have gas for domestic purposes for one family, the lessor paying for connections at such points as may be from time to time designated by lessee.

The above rental shall be paid to lessor in person or by check deposited in post office direct to . And it is further agreed that lessee shall have the right to surrender this lease upon the payment of dollars, and all amounts due hereunder and thereafter shall be released and discharged

from all payments, obligations, covenants, and conditions herein contained, whereupon this lease shall be null and void, and that all conditions, terms, and limitations between the parties hereto shall extend to their heirs, successors, personal representatives, and assigns.

Lessor agrees that the recordation of a deed of surrender in the proper county and a deposit of all amounts then due hereunder to lessor's credit in Bank shall be and be accepted as full and legal surrender of lessor's rights under this lease.

IN WITNESS WHEREOF. We, the said parties hereto, have hereunto set our hand and seals the day and year first above written.

Valuation of Oil Properties, Lands, and Royalties. — The valuation of oil properties demands skill and experience which only long practical training can develop. A competent engineer can value the plant by an inspection, but in estimating the present value of oil wells and partially exhausted territory, only long and wide experience can be of use. An examination and dissection of carefully compiled records, whilst exceedingly useful, may prove very dangerous unless correctly interpreted in connection with other data. Book-keeping works wonders with figures in skilful hands, and one may easily be led astray by the proverbial red herring.

In considering the future value of a property, neighbouring operations must not be overlooked, and the extent and nature of the development of adjoining lands must be investigated. Petroleum being a liquid is unlike coal and solid minerals which nothing but a veritable catastrophe will transpose from the spot where they rest till attacked by miners; as a mobile fluid oil is readily deflected, easily missed by careless drilling, and its sources are open to the hostile invasion of water which may defy all efforts to control.

The valuation of machinery and buildings needs no comment as it is a normal engineering problem requiring only special knowledge where drilling tools and accessories are involved. Oil wells assume a different aspect, as vendors usually endeavour to inflict upon purchasers their full initial cost, arguing that they can be deepened or the casing can be withdrawn, or that their life is perpetual.

Prolonged and involved negotiations often precede a sale of a producing property, especially as the transfer of a large undertaking is rarely effected on a sole cash basis. Usually an interest is

retained in shares and debentures or bonds that constitute a prior charge on the profits and sometimes assets of the company till redeemed. Shareholders of the original company thus receive a cash payment and a share distribution, the latter acquiring a marketable value that enables participants to realise their holdings and sever their connection with the concern if they so desire. An American practice is to amalgamate properties and make a bond issue to pay the cash purchase price and provide the working capital, this sum usually approximating to the reasonable valuation of the property. Ordinary shares are then distributed as a bonus to subscribers of bonds and retained by the promoters as their profits. This principle is open to grave objections, as (1) it gives to the promoters any high profits that may accrue from trading; (2) it makes the raising of subsequent capital difficult, and if so raised, depreciates the bonds or preference holdings; (3) it encourages extravagant development and unwise distributions of dividends to lift the market value of the ordinary or deferred shares.

Cash and share purchase considerations are given quite different values in sale negotiations, but the proportion must always be the subject of negotiation between vendors and purchasers, and be decided on the merits of the property or the projected transaction. Special attention should be directed to the question of royalties in valuations of oil properties or lands, as these comprise an increasingly heavy burden on producers as the age of the properties increases.

There has been some inclination in America to value properties by oil content, but for reasons given elsewhere (p. 159) the dangers attending this course are great. Many properties could be named where the extracted oil must exceed the original oil contents by several hundred per cent., assuming the almost prohibitive thicknesses and impregnation of sand. In certain oil-fields where the inclination of the strata is small, the density of the oil is such as to restrict lateral movement, and the sands are comparatively regular in thickness and consistency, some approximate figures may be arrived at by assuming a possible percentage extraction.

A practice that has acquired some popularity in the central

oil-fields of the United States is to value producing properties at some sum, varying with the price of oil, per barrel of settled production per diem. The dangers that beset this course lie in fixing the settled production, and in the amount of reserve territory. Exhaustion is so rapid in many of the oil-fields where production is only obtained from the compact sands by heavy blasting, that the terms flush and settled production need proper definition.

Producing properties supporting royalties of from 10-15 per cent. have exchanged hands on a basis of from $300 to $1,000 per barrel per diem of settled production. As the average production per well and the distribution of wells were roughly known, it was possible to estimate approximately from the quoted price the amount of developed area involved in the transaction. If this proved reasonably correct only the reserve territory would need investigation.

Californian oil lands were frequently sold outright on a cash basis per acre without reservation of royalty. Plots of 40-640 acres and even big ranches of many thousands of acres were disposed of first for $5 an acre, then by increments as operations extended until $500, $1,000, and even $5,000 per acre were obtained. In 1912 the Californian Oil Fields, Ltd., paid £117,600 ($565,000) for 480 acres in the Coalinga field; and the Shell group later bought out the interests of the Californian Oil Fields, Ltd., for the equivalent of £2,600,000 ($12,500,000) with a settled production of about 11,500 barrels a day, equivalent to a price of $1,100 per barrel of settled production.

The Oil and Gas Journal of April 1914 reported that in the Panuco district of Mexico an American paid $10,000 (Mexican) for half a hectare plus one-third royalty. Also that 4 ha. had been purchased for $27,000 plus one-fifth royalty.

One select area of proved value in the Baku oil-fields with well-sustained production and nominal royalty was sold for as much as £18,000 ($86,500) per acre, but this is a price which possibly constitutes a record, although subsequent events showed it was more than justified, perhaps to the amazement of the vendor. In Roumania and Galicia plots practically proved by neighbouring operations and subject to a royalty of from 8-15 per cent. are

often sold at a figure of from £40 to £600 per acre, according to the richness of the particular area in which they lie. Unproved territory, where geological conditions are favourable, often realises from £4 to £40 per acre, with a 5-10 per cent. royalty.

Valuers of oil properties should not be beguiled into the belief that properties are not impoverished to the extent of the quantity of oil already abstracted, and it is absurd to assume that production can be maintained indefinitely. The number of distinct oil horizons is an important factor, and the grade of oil and market conditions must be considered in arriving at an average value over a period of years.

In extensively operated oil-fields an approximate total average production per well is known, so that a proportionate value and yield ratio may be often calculated and applied.

Working costs are naturally an object of investigation when estimating the prospective profits of a property under acquisition, and in this connection wide differences of opinion exist as to what is capital and what is revenue expenditure. Unfortunately, the regrettable practice of charging drilling expenditure to capital and applying some depreciation factor is generally persisted in, possibly because it is a conveniently flexible amount that can be applied in a variety of ways to obscure the trading account. It matters little how the expenditure is distributed, provided the cash needed for drilling is provided out of revenue, as drilling is performed to maintain production, and so is a fair and proper charge on production.

The practice of building up a large capital account, showing substantial working profits, and distributing dividends provided by the periodical raising of fresh capital, is reprehensible, yet a common but cleverly disguised feature of oil finance. Of course a day of reckoning comes when capital has mounted to unreasonable figures, whilst the properties are actually depreciating in value, profits are more difficult to show, and new capital is not readily subscribed.

It cannot be too strongly emphasised that the cost of drilling is a fair charge on revenue, as without drilling production disappears, and it should therefore be annually charged up to production, instead of being concealed in some general depreciation

account as is so often the case. Drilling costs are usually the heaviest charge on production, and they should be arrived at by dividing the sum expended by the year's output.

Some oil companies have always continued the admirable practice of charging up all drilling expenditure to revenue, and in other departments endeavours are made to adjust depreciation so that it provides sufficient to maintain and replace all machinery. A new and larger basis of operations, if provided for out of revenue, is a justifiable reason for the readjustment of capital account.

In investigating oil properties, the author always separately divides capital and revenue expenditure under some eight or ten main sub-heads. By the side of each heading on the capital account is placed the depreciation allowed, and if drilling is included, the amount per unit of output for the year involved is added. The revenue statement is likewise filled up with the annual expenditure under the various headings given, and against each

CAPITAL EXPENDITURE STATEMENT.

Description of Property.	1914.			1915.		
	Valuation.	Depreciation.		Valuation.	Depreciation.	
		Amount.	Per Cent.		Amount.	Per Cent.
	£ s. d.	£ s. d.		£ s. d.	£ s. d.	
Buildings and constructions -						
Oil wells in exploitation						
Drilling, deepening, and repairing wells during year -						
Pumps, pipe lines, pump stations, water, and oil -						
Drilling tools -						
Engines and boilers -						
Workshop machinery and tools -						
Tanks and reservoirs -						
Electric installations and fittings -						
Transport animals and appliances -						
Materials in store -						
Properties -						
Total value inventory -						

REVENUE EXPENDITURE STATEMENT.

Description of Property on which Expenditure Incurred.	1914. Production.		1915. Production.	
	Amount.	Per Barrel.	Amount.	Per Barrel.
Bailing and pumping charges				
Repairs and renewals—				
Wells				
Engines and boilers				
Pumps and pipe line				
Electrical installation				
Fuel or power				
Rents and royalties				
Administration and office expenditure				
Taxes				
Sundries				
Cost of production				
Depreciation				
Total cost of production				

is the worked out cost per unit of production. Comparison of several years in this way discloses any extraordinary feature that might be missed in the analysis of accounts of a single year. The true actual cost of production is then the sum of revenue charges and the drilling charges, and if the depreciation allowances do not closely correspond with the capital outlay to maintain the plant whilst production has been practically stationary, it is clear that insufficient has been allowed in the accounts.

Attached are two forms for tabulating data when analysing the accounts of a company for valuation as a going concern. Items would be modified to suit local conditions and the methods of book-keeping adopted, but at least three years should be so treated to obtain average results. Depreciation is transferred from the capital account to the revenue account, where all figures are divided by the year's output to find the cost per unit of production.

Great variations occur in the cost of production, including the amount expended on drilling to maintain output. The most startling in low cost to come under the author's notice in his

professional work was a property where only a few thousand pounds were originally subscribed, and since that date revenue had provided for all requirements, whilst enabling large dividends to be paid. All costs amounted to under 10 cents per barrel, or 3s. per ton. One rig was sufficient to maintain a yield of about 200 tons (1,400 barrels) daily, as well as clean out the wells, and there were eleven men on the property including the manager and drillers. There was no royalty payable, and natural gas from the well provided all fuel.

The heaviest costs of production are probably in the Baku oil-fields of Russia, where both the system of drilling and extraction of oil are costly. In 1914 the cost of extraction could be estimated at about 23 copecks per pood (30s. 8d. per ton), and the drilling charge at about 12 copecks per pood (16s. per ton), making with other expenditure a total revenue charge of 35 copecks per pood (46s. 8d. per ton). Taking the best period of the Galician oil-fields, when deep wells cost £12,000 ($57,600), and gave ultimate yields of, say, 40,000 tons (300,000 barrels) of oil, the depreciation charge would be $\frac{£12{,}000}{40{,}000 \text{ tons}} = 6$s. per ton, or say 19 cents per barrel.

Exceptional gushers must be excluded from calculations of prospects. In cases like the Colombia well of Roumania, and the big wells of Russia, Mexico, etc., the total cost of production may, for the time being, be less than one shilling per ton (3.2 cents per barrel).

If oil properties are not supplemented to provide for approaching exhaustion of the older areas, depreciation should be allowed on the capital value of the lands. It is doubtful whether this point is as widely appreciated by shareholders of oil companies as by investors in mining concerns, where the life of the mine can be roughly foreshadowed, and is constantly kept in view.

Purchase of royalties should only be made under professional advice, as their valuation is a difficult and intricate matter calling for long practical experience and sound judgment. Trading in royalties is a recognised practice in some of the oil countries, and they there acquire a value mainly determined by fancies or expectations, often as a consequence of more or less obscure information surreptitiously obtained through devious channels. The

highly speculative nature of royalties, and the constantly fluctuating value arising from variation in production or prospects of the well or property dealt in, or even neighbouring properties, presents a field for speculative transactions equalled by few gambles.

The number of variables in calculating royalties gives endless scope for individual fancies. The value of a fixed percentage royalty in kind is dependent upon—

(*a*) Price of oil.
(*b*) Production of wells.
(*c*) Grade of oil.
(*d*) Dangers from fire, damage or intrusion of water.
(*e*) Activity or skill of lessees.
(*f*) Energy of neighbours.

Fixed sums per unit of volume or weight naturally eliminate some of the uncertainties of royalties.

The method of arriving at a valuation of royalties will be deduced from the above, and a cautious valuer will only admit of the use of average figures throughout, fortified or depressed for any other justifiable reason.

How dangerous yet seductive royalty anticipations become when submitted by plausible but dishonest brokers to the ignorant, although supported by a mass of quite correct data, the author has had opportunities to learn. On one occasion a large number of royalties in kind on important producing wells were offered at what appeared a most tempting price. An investigation, however, disclosed the fact that the royalties were on new wells giving a large initial or flush production, which would inevitably show a rapid fall in the near future. A further calculation showed that the production, although correct at the moment, would, if continued at the same rate for a year, exceed the entire annual output of the country in which the wells were located.

Oil-Field Waste and its Prevention.—In no commercial operations has there probably been greater unjustifiable waste of the resources of Nature than in oil-field development, some idea of which will be gleaned from occasional references in preceding chapters. In other mining operations, wasteful methods or processes do not entail permanent loss to mankind, as picked mines or discarded dumps may enable work to be repeated with

advance of science or improvement in value of products. Initia operations in new oil-fields, where uncontrolled work was allowe to proceed without criticism, has led to hundreds of thousands o tons of petroleum being lost by fires, evaporation, or dissipatior amidst surface beds from which it can never be recovered. Millions of barrels of oil have been deliberately burnt as the most economical way of disposal, and many millions of tons of oil could have been saved by simple and obvious remedies, at the time considered unworthy of serious attention.

For many years the residuals of Russian oil, which later became the main support of the industry, were a costly burden and absolute annoyance to Baku refiners, who burnt them in open pits. At a later stage it was the benzine and intermediate oils which were dregs in the industry, and these were burnt as fuel for the operations. As late as 1905 benzine, which is now the most sought-for product of petroleum, was burnt as fuel in most oil-fields, and its suddenly acquired value upon the advent of the motor car transferred prosperity to many struggling concerns producing light oils.

The reduction in the yield of wells, the increased working costs, and the enhanced value of petroleum have stimulated economies, although there is still a wicked waste of products which will one day command much higher prices.

The chief directions in which economies are being made are :—

(*a*) Fuel consumption and economies in production.
(*b*) Prevention and restriction of fires.
(*c*) Control of flowing wells.
(*d*) Preservation of the lighter products by reducing evaporation losses.
(*e*) Scientific distribution of wells to utilise to the full the natural gas pressures.

Fuel consumption is enormous as a rule in the richer oil-fields, and a mere percentage scarcely conveys any idea of the extent, owing to the great variation in the yield of wells. The loss is much greater than is apparent, as the fuel on the oil-fields is usually crude oil, and the most desired and highest priced products are therefore consumed, instead of confining fuel to the least valuable constituents of the oil. Economies are being made by the

extended employment of internal combustion engines, both gas and oil, and improved methods of extracting oil.

The wasteful methods on oil-fields were vividly illustrated in the Baku oil-field, where a contractor, only a few years ago, paid the authorities a substantial sum to recover the oil from the drainage of the oil-field. This contractor recovered 15,000 tons (112,500 barrels) of oil annually by simply passing the drainage of the oil-field through water traps. From a dam on the Kern River, California, as much as 250,000 barrels of oil have been collected in eight years.

Great advances have been made in preventing and restricting the spread of fires, which have often consumed many thousands of tons of oil within an incredibly short time. Improvements include more strict legislation about lights, fittings, and smoking, also the increasing use of iron derricks or wooden derricks protected by non-inflammable material.

Flowing wells are now better controlled, either by restricting the flow of oil, or diverting it in a way to ensure safety from fire, and diminution of losses. In some of the important oil-fields, indications of a possible flow are sufficient pretext for prohibiting further drilling operations until approved provision for the collection and disposal of the oil is made.

About the years 1890-1900 it was no uncommon occurrence for wells yielding 10,000-15,000 tons (75,000-112,500 barrels) daily to burn for days or weeks, and the author has himself seen three great eruptive wells burning contemporaneously in the Baku fields. Enormous losses have been sustained by Roumanian producers before stringent regulations were imposed on operators; and in Mexico the loss of oil from the famous Dos Bocas well was estimated at 1,000,000 tons (7,000,000 barrels).

Lighter products of the oil are saved by quick transfer of the crude oil to tanks or storage provided with protection from the sun's rays. Brief exposure to the atmosphere, especially if there is a wind, causes alarming losses of light density oils through evaporation. Large surfaces are avoided as much as possible when limited exposure cannot be prevented, to effect settlement of sand or water.

Oil is often pumped direct into storage tanks without exposure to the atmosphere, the tanks being provided with hermetically

sealed roofs, and the oil being led through a pipe to the edge of the tank to avoid agitation and facilitate absorption of lighter products in the bulk.

In the early period of developing new oil-fields, losses by evaporation and soakage are often enormous. Storage is usually hastily prepared by damming depressions or excavating large earthen tanks, into which the oil is conducted and allowed to stand. In sandy soil the percolation is very great, and in all cases the evaporation is considerable. Unskilfully designed dams often break with the first heavy rains. The Gulf of Paria, Trinidad, has twice been covered for miles with oil which had escaped to the sea as a result of collapsed dams, and the Caspian Sea has many times been covered for miles by uncontrolled flows from the Bibi-Eibat oil-field.

Superstition often prevents provision for flowing wells beforehand, but rarely are eruptions so sudden or fierce that some controlling device cannot be quickly arranged. Anxiety to see oil above ground, even though unmarketable, is responsible for heavy losses, as obviously the best and safest reservoir of all is the earth, and it is preferable to leave it where it can sustain no loss until provision has been made for disposal.

If the waste of oil has been great, the waste of natural gas has been far greater. Oil from flowing wells is practically always accompanied by much gas, and it was formerly allowed to escape into the atmosphere. Even to-day comparatively little use is made of the natural gas accompanying oil, owing to the absence of facilities for transporting it to points of consumption. Under normal bailing conditions 30,000,000 cub. ft. of gas would be a low estimate of the quantity daily wasted in the Baku oil-fields, but a single eruptive well would yield nearly this amount. This quantity of gas still goes to waste, although the fuel consumption is often 20-30 per cent. of the production of crude oil.

In fields like that of Moreni, Roumania, the volume of gas escaping into the atmosphere would certainly yield all the power needed in that field if collected and directed to use, and the same could be said of other fields. The most serious waste has, however, taken place in some of the American fields where, in the search for oil, gas sands have been struck, and yields of

from 10,000,000-20,000,000 cub. ft. of gas daily allowed to escape. More natural gas is wasted in some of the American fields than would supply the whole of London, and even when directed to use it was the extravagant practice to leave flares burning night and day in the streets of towns within gas zones. In the early part of 1909 it was estimated that 70,000,000 cub. ft. of gas, equal in heating value to 1,500 tons of crude oil, were daily wasted in the Caddo oil-field of Louisiana, and wells in Ohio and Kansas were allowed to discharge into the atmosphere 25,000,000 cub. ft. of gas daily, equal in heating value to 550 tons of crude oil.

Much dissatisfaction was felt in America at the enormous waste of such an ideal fuel as natural gas, and in 1913 the Bureau of Mines of Washington was constrained to investigate the matter in Oklahoma, where, in the newly developed oil-field of Cushing, gas wells of 20,000,000-40,000,000 cub. ft. daily capacity were intentionally allowed to flow to waste before drilling into the deeper oil-yielding sands In April and May 1913 it was said that five wells were daily discharging not less than 126,000,000 cub. ft. of gas into the atmosphere, and one well alone yielded 1,500,000,000 cub. ft. of gas before being shut in. Such stupendous figures cannot be realised until converted into oil or coal equivalents. From the latter mentioned well alone the heat value of the gas would be equal to about 34,000 tons (255,000 barrels) of oil or 50,000 tons of good coal. No wonder the Washington Government is concerned at the wanton waste of fuel, the main support of every industrial country, and ignorance alone will explain the attitude of landowners or lessors who quietly submit to their lands being depleted of products which one day will be appreciated at their proper value.

Investigations have shown all this waste of gas to be quite unnecessary, and that the strongest gas sources can be shut off and passed, and their flow controlled by suitable measures. These are explained on p. 392.

The suggestion has been made of storing surplus gas from oil or gas fields by its readmission to exhausted oil or gas sands on other areas through old wells. This procedure should be quite feasible if suitable measures are taken to seal wells piercing

these abandoned horizons, and enormous natural reservoirs would then be utilised in the same way that flood water is now returned to the chalk in the London basin to counteract the continually falling level of water. In 1915 surplus gas was in this way returned to the earth in the midway-sunset oil-field of California by one of the leading companies.

In reviewing the subject of oil-field waste Arnold and Garfias express the opinion that not more than 40-50 per cent. of recovered oil reaches the market. They estimate that in California from 50-60 per cent. of the petroleum contents of the sands is extracted, and that evaporation and seepage losses amount to 10-15 per cent., and that fuel consumption amounts to 8-10 per cent.

CHAPTER III.

GEOLOGICAL STRUCTURE AND LITHOLOGICAL CHARACTER OF OIL-FIELDS, AND FACTORS GOVERNING THE DISTRIBUTION OF PETROLEUM.

Factors Governing the Formation, Accumulation, and Preservation of Petroleum—Character of Oil-Bearing Strata—Migration of Petroleum—Causes of Pressure—Subterranean Movements of Petroleum Occasioned by Development—Area Influenced by Producing Wells and their Spacing—Yield and Life of Oil Wells—Production and Life of Oil-Fields—Typical Well Logs.

Factors Governing the Formation, Accumulation, and Preservation of Petroleum.—Commercial supplies of petroleum are restricted exclusively to strata of sedimentary origin, thus differing essentially from metallic minerals, which are mainly derived from igneus intrusions, except where occurring as secondary deposits. Not only is petroleum confined to sedimentary strata, but it is beds of a comparatively recent geological age, the Tertiaries, which yield the bulk of the oil of the world to-day. With the possible exceptions of coal and iron, oil-fields are rarely coincident with mining areas.

It is quite certain that natural petroleum, whilst sometimes having an obviously adventitious origin, was more often formed in the series of beds in which it is now found when they were horizontally disposed; but as petroleum and gas are fluids, and obey the laws of fluids, their present distribution has been influenced by terrestrial disturbances which have from time to time thrust the containing strata into irregular contortions. Continuous or successive earth movements, especially in the neighbourhood of mountain ranges, have not only given the beds an inclination in certain directions, but have caused the strata to assume wave-like forms in adjusting themselves to crushing forces.

The ordinary anticlinal and synclinal structure is a normal consequence of such forces, and the axes of anticlines usually run approximately parallel with mountain ranges. The oil-fields of

South Russia lie parallel with the Caucasian Mountains, those of Roumania and Galicia follow the curve of the Carpathians, and the Burma fields run parallel with the Yomas. The Peruvian oil-fields flank the Andes, the Pennsylvanian fringe the Appalachian Mountains, the Californian the Rockies, and the Italian the Apennines.

Rarely is this simple structure unaffected by secondary movements in other directions, or by numerous faults which not only complicate the structure, but have an important bearing upon the distribution of the fluids the beds contain. The distribution of water, the only other fluid which circulates freely in the earth, is well understood, but the movement of petroleum, being a viscous liquid, always accompanied by gaseous products, and often commingled with water, introduces much more complicated problems into its study. Quite apart, however, from the effect of structure on the segregation of petroleum, it is these crushing forces and consequent denudation which have brought the productive beds sufficiently near to the surface to disclose to the geologist their presence, and to enable them to be reached by appliances at the disposal of man. The inclination imparted to thousands of feet of sedimentary strata by thrusting forces has alone enabled measurements of the thickness of beds to be made, depths of strata to be learned, the relative age of the strata to be ascertained, and key horizons to be noted for identification during drilling in less disturbed localities.

The greatest service rendered by Nature, beyond actually disclosing the existence of oil beds, is the concentration of petroleum in certain spots, or "pools" as they are often termed, where operations can be centred. Where a series of strata containing petroleum have been folded, or inclined, creating certain structures where the escape of oil or gas was entirely or partially arrested, concentration has frequently occurred, and it is in such localities that many of the great oil-fields of the world are located. Where there are defined anticlines and synclines, it is along the crest and the near flanks that oil and gas have generally concentrated under great pressure, and it is in the synclines that the greatest quantity of water, or perhaps only water, is found.

The forces which have operated in producing the separation and concentration of oil are imperfectly understood, although it is usual to attribute to gravity the chief cause. In some districts elevations in the stratum of from 10-100 ft. coincide with accumulations of gas or oil, or both, in the higher points. The Appalachian fields present classical examples of this action, and the anticlinal theory of oil concentration has been so well developed and applied there that numerous oil pools have been opened up as a result of geological evidence and careful levelling. On some folds gas under high pressure alone fills the crest, whilst the flanks yield oil, indicating a separation of gas from the oil as well as oil from the water, but such is not always the case.

In all sedimentary strata there must occur the water of sedimentation, which, in the case of great thicknesses of sands, is considerable. Until elevated above sea level or thrown out of a horizontal position the fluid contents will continue to occupy their original ground, but when an inclination is imparted to the beds there would be a tendency for the water to sink if it could thereby displace any lighter fluid, causing such latter to concentrate at the elevated points. Without water no concentration could be effected, as under such circumstances any liquid would naturally collect in the depressed or synclinal parts, and gas only would tend to occupy the higher spots or anticlinal crests. In fact, in the absence of water, it would be the syncline in which one would drill for oil, and in reality there are areas within the Appalachian oil-fields, where the anticlinal theory is especially applicable, which exhibit this synclinal oil.

Some importance must be attached to the retention of water of sedimentation in the great geo-synclines with which the oil-fields are so often associated. The Appalachian field is a typical example of this, and in consequence the strata have been but slightly subjected to the action of atmospheric or other circulating waters, and although possibly slow and occupying vast periods of time, the concentration has been carried on with little change of the character of the oil as well as slight loss.

The occurrence of rich supplies of petroleum near the crests of folds with flanks dipping but a few degrees from horizontal,

suggests other causes than gravity for its migration and concentration, and it is possible that gas, capillarity, and the peculiar affinity of clay for oil, and other forces discussed on pp. 122-23, may play contributory parts. Emulsions have been suggested as a means of facilitating interchange, and it is useless to disguise the fact that little is yet known about these peculiar mixtures of water and oil which present such difficulty to separate when they are found in oil-fields.

It is certain that the density and viscosity of disseminated oil influence largely the degree and extent of concentration. Heavy oils of a density closely corresponding to that of water, and having a viscosity which will barely allow them to flow at normal temperatures, cannot obey laws which would apply to oils 15-20 per cent. lighter than water, and little if at all more viscous than water. Thus in practice heavy asphaltic oils occur in somewhat different surroundings to light oils.

Extended experience is convincing the author that implicit reliance on the anticlinal theory is leading to errors by inexperienced and text-book prospectors. Concentration can be effected without anticlinal structure, and operators in many oil-fields have flung discretion to the winds, challenged professional advice when tendered, and cast their prospect wells far away from the crests of anticlines, sometimes with remarkable success. In Russia, Roumania, California, and Peru, prolific fields are being worked on slightly inclined monoclines that could scarcely be termed the extended flanks of anticlines, where consistency of results over wide areas causes theorists to hesitate in advancing hypothetical reasons for local saturation. Inclinations are often so slight that migration will not account for concentration of oil, yet the anticlinal theory is clung to with a pertinacity that is often surprising.

The Maikop field of Russia (Fig. 39) was subjected to severe criticism because its structure did not conform with conventional ideas, yet, from a single pool, situated on a monocline, had been extracted up to January 1915 the large amount of 11,000 tons (82,500 barrels) of petroleum per acre from a sand averaging only 35 ft. in thickness. One of the early wells gave at least

50,000 tons (375,000 barrels) of oil within a few months, and in 1915 a well on the northern extension of the pool gave 70,000 tons (525,000 barrels) within five months.

Accumulating data tend to confirm the belief that exploitation often creates an area of high saturation of oil by inducing a flow of gas and fluids to points of reduced pressure. As the great wells are nearly always sunk at the points where the beds are most easily reached, that is near the crest of anticlines, this area automatically acquires a position of prominence that no other attains to. Subsequent drilling on the near flanks is attended by less success, and it is at once assumed that they were always less prolific. Had initial wells been sunk at points on the flanks, these latter areas would probably have been converted into the points of maximum saturation. The details given in pp. 134-37 better explain the movements alluded to and their causes.

Attention has been rightly called by Leonard Dalton[1] to a feature which may in some cases have determined definite lines of oil pools quite independently of structure. In discussing the possible origin of oil, it is suggested that currents may have led to the deposition of oil-forming material along definite belts, thus confining oil-producing and oil-concentration conditions to regions of restricted lateral dimensions. Such results would not be inconsistent with the disclosed facts, as currents would often approximately follow the direction of tectonic folds, and produce the parallelism to mountain ranges such as is observed.

Subsequently Rowell H. Johnson has shown how these conditions apply to the Mid-Continental field of North America, and he has called attention to the analogy of such elongated "sand bodies" with the formation of barrier beaches and offshore bars along the Atlantic coast of the United States at the present day.[2]

The main sand of the Shirvansky pool of Maikop is elongated in the direction of dip, and appears to represent the deposit of a river that flowed southwards in late Eocene times.

[1] *Economic Geology*, Vol. IV., No. 7, 1909.
[2] *Economic Geology*, Vol. VI., No. 8, 1911.

Petroleum was doubtless, in most cases, formed before the beds were disturbed from a horizontal position, and in the case of the lighter oils, where it was sparsely distributed over a wide area. Finely divided oil particles distributed over an area of many miles would, if concentrated into a narrow strip of two or three square miles, constitute important supplies. A single bed 100 ft. thick, containing only 1 per cent. of oil by volume, would hold in the aggregate about 5,000,000 barrels (say 670,000 tons) of oil per square mile, enough to saturate 3,200 acre-ft. of sand of 20 per cent. capacity.

Elevation may have been constant or intermittent. In the Bibi-Eibat oil-field of Baku there is evidence of three well-marked unconformities in the Pliocene escarpments that half encircle that field, and in the Peruvian oil-fields three table lands of successive elevation bear witness to movements subsequent to the deposition of the oil beds which they invariably overlie.

A predominance of impervious beds is an essential feature of the strata in all rich oil-fields. Their duty has not been confined to the retention of oil within the series during earth movements, but they have often been closely associated with the formation of the oil. Thick beds of clay or shale are the usual coverings to oil beds, and although the latter are sometimes very sandy, they are nevertheless fairly impermeable in character. Quite distinct from their impervious quality, clays and unconsolidated shales sustain less fracture when thrust into folds and intricate forms by earth pressures; in fact, sharp overfolds may be seen in which distorted lenticular bodies of oil sand are encased in an almost undisrupted matrix of clay.

Arenaceous strata saturated with water might, under certain circumstances, form impervious coverings to beds where the necessary material for the formation of petroleum existed, but any earth movements would cause the fracture of sandstones, and sufficiently disturb some sands to permit the escape and dissipation of contained oil. The impervious quality of clay is in reality due to the presence of occluded water between the particles, in the same way that air is the non-conducting medium in heat-insulating materials. Clay is a hydrated silicate of alumina that loses its

impermeability when dried. Its plastic nature may be increased by colloidal matter.

Oil-measures, as they have been appropriately termed, often attain a considerable thickness, in which clays, shales, sands, and sandstones alternate. Sometimes many hundreds of feet of barren clays or varied strata separate productive beds, but in other cases nearly every porous stratum within certain vertical limits yields oil. In some fields practically all the beds for thousands of feet are more or less petroliferous, but in other regions dry beds with no trace of oil are passed between successive productive seams. Some intermediate sands are saturated with water, and its exclusion is often a tedious and costly operation necessary for the protection of the oil sands amidst which they occur. These waters are discussed elsewhere. In certain oil districts structural features play a quite subordinate rôle to lithological character. This is especially noticeable in Kansas-Oklahoma, where almost horizontal beds continue over vast areas, and oil is exclusively confined to one or several sandy horizons traceable over long distances.

Remunerative yields of oil have been obtained through a vertical thickness of about 3,000 ft. on the Baku oil-fields of Russia. In the Yenangyaung oil-field of Burma, about 2,500 ft. of strata have yielded commercial supplies of oil.

The Carboniferous and Devonian oil-fields of America are characterised by commercial supplies of oil and gas being confined to lenticles or streaks in a few persistent strata, without which little or nothing is found, the oil-forming conditions only occurring during small periods of geological time at varying and long separated intervals.

Tertiary oil-measures often disclose a considerable vertical range, but an horizon of maximum productivity is observable in most oil-fields. Down to a certain depth sands increase in productivity, then follows an area of maximum saturation, after which production decreases or ceases, and water is found in increasing quantities. Many great oil-fields have exhibited the above phases, but in some cases two or more oil-bearing series of strata have been discovered separated by a thousand feet or more of barren beds.

Productive zones may reach a vertical thickness of 2,000 ft., but where the strata are inclined the depth of productive strata pierced by drilling would naturally far exceed the above amount.

The author, in 1901, experienced the disappointment of passing from the oil-saturated zones to the water horizons underlying parts of the Baku oil-fields. Within defined limits wells drilled to a certain depth gave practically no water, and nearly exhausted oil sands could be relied upon to give yields of from 5-10 tons (37-75 barrels) daily, with a head of a few feet only. At a certain known point rich oil and water sands were indiscriminately mixed, and high levels of either liquid were immediately recorded. Extraction of fluid, however, invariably drew in water at the expense of the oil, and the level could not be considerably diminished by heavy bailing or pumping. A succession of widely-spread wells confirmed the existence of basal water, which definitely sealed the vertical limits of exploration, although oil sands did exist amidst the water strata, and richly impregnated oil sands were often raised in drilling, through a high column of water that could not be isolated.

In many oil-fields unconformities fix the limits of drilling instead of reduction of yield, and in Roumania the occurrence of a few known fossils often saves the drillers a great deal of waste work in barren strata by indicating the penetration of another geological series.

There are reasons for believing that it is more than a mere coincidence that so many of the great oil-fields of the world are associated with Tertiary strata of distinctly deltaic character. Strata of greater age are as frequently exposed along the flanks of the same mountain ranges as the Tertiary oil beds, and their tectonic and lithological character is not always inconsistent with the accumulation and storage of petroleum. So closely does the petroleum geologist associate oil with the Tertiary bad-lands variety of landscape, that interest is almost instinctively aroused when thrown amidst such surroundings. The unconsolidated, yielding, and readily disintegrated clay-shales are the cause of the terrible mud which characterises many Tertiary oil-fields in the wet seasons, and are the direct cause of the frequent landslides

which introduce so many mechanical difficulties, and impose sucl heavy expense in the hilly districts.

The limited area of oil-fields as compared with, say, coal fields, points to a much greater restriction of the condition favourable to the formation and accumulation of oil than coal That oil-forming conditions disappear within short distances i illustrated by the fact that areas equally favourable from a geological point of view for the accumulation and preservation o oil are found barren, or almost so, a short distance along ar anticline highly productive of oil. A second parallel anticline differing little in general features, is often unproductive, and woul have been expected to have yielded oil had there been a per sistence of oil-forming conditions.

Lateral variation, which is so common a feature in Tertiar oil-field strata, is typical of the deltaic conditions under whicl petroleum is found. Exposures in most of the oil-fields giv abundant evidence of the lenticularity of sands on a scale onl commensurate with currents that would be unlikely under dee water conditions. On the larger scale a series of beds may b traced, gradually losing or acquiring an arenaceous character i certain directions, and consequently diminishing or improvin opportunities are afforded for the accumulation of oil provide the conditions of formation are not varied.

Character of Oil-Bearing Strata.—Although sands and sand stones are the chief oil reservoirs in oil-fields, the intervenin shales or clays are often impregnated with oil, and may hav often been the media in which the oil was produced. Wher much crushed into sharp folds, outcropping clays are some times seen to have innumerable slip or cleavage planes alon which films of oil occur. Seams of sand, a mere fraction of a inch in thickness, and lenticular in shape, are often the receptacle for oil, and every fault plane with only a few inches of dis placement is full of oil. Distributed in the clays will ofte be observed tiny lenticles of dry sand which have someho escaped saturation like other sandy parts, thus disclosing som selective properties of the oil or water contents.

Some clays and shales within an oil zone have innumerabl

leavage and slip planes impregnated with oil which has suffered ome physical change during its movements, or in its present nvironment. Great viscosity has been imparted, probably as the esult of absorption of the lighter products, causing the remaining lms to draw out into innumerable almost microscopically fine, air-like fibres, when a parting plane is cautiously separated. A ery beautiful and striking effect is produced if a suitable light is ast on these minute hairs that often retain their continuity nbroken for several inches.

Even amidst dark stained sands more or less impregnated vith oil there are often distinct layers of sand devoid of oil, nstained and quite dry, having in some way escaped contamina-ion. Masses of sand discharged from flowing wells, or raised n sand pumps during drilling, reveal this same peculiarity of rregular discoloration.

However petroliferous in character deposits of clay or sandy lay appear, they very rarely yield commercial supplies of oil, wing to the high resistance to any movements of liquids vithin their pores. Fault and slip planes in such strata may ecome the media for collections and movements of oil, but vith this exception they are never a source of important supply. Even thin beds of sand rarely produce large amounts of oil nless fed by thicker deposits near by. It is the thick beds vhich, before dislocation, extended for long distances, without reak, that are the chief oil containers, although they have often, t a later date after impregnation, been isolated into sections y faulting.

The only other important source of petroleum is limestone, rom which the oils of some of the Appalachian, Texan, Canadian, Mexican, Egyptian, and Persian oil-fields are obtained. Sands, sandstones, grits, and gravels yield the great supplies of oil produced by Russia, Roumania, Galicia, Burma, Borneo, Peru, Italy, and Trinidad. The oils of California, parts of Texas, Illinois, many of the Appalachian fields, and Kansas-Oklahoma are also derived from arenaceous strata.

Arenaceous Oil-Bearing Strata.—Sands, gravels, and grits, being generally shallow-water sedimentary deposits, are naturally

Plate VII.

Fig. 5.—Section of Oil-Bearing Strata on Island of Cheleken, Caspian Sea.

Showing amongst other features the causes of irregular distribution of petroleum and variable depths and thicknesses of beds, and how fault planes may affect the production of wells. Similar features characterise most oil-fields where the beds are much inflected, and the reasons for widely differing logs of neighbouring wells are apparent.

[*To face page* 104.

more erratically deposited than clays, marls, and limestones of sedimentary origin, which are essentially deeper water depositions, and less subject to currents of variable intensity, duration, and direction. The fact that oil is mainly derived from arenaceous beds would, therefore, afford a partial explanation for the somewhat erratic distribution of petroleum, but the prevalence of deltaic conditions in many oil-fields imparts further irregularities that mystify the operator and perplex the geologist.

A cursory study of deltaic conditions affords explanations for many apparent inconsistencies in oil-field prospecting, and should cause geologists to make their prophecies with reservation where such geological conditions pertain. False bedding often asserts itself in a way that demands a vivid imagination to explain its occurrence. Thick banks of sand of irregular but usually lenticular shape are flanked or surrounded by finer sediment, shell beds, argillaceous deposits, or even vegetable matter. Lignitic bands of a more or less argillaceous nature may cover a wide area, or they may fill depressions, or fringe old river banks. An examination of any large delta will provide data enough to explain many of the disappointments, quite apart from structural features, which often introduce additional uncertainties.

Oil sands frequently vary considerably in quality, composition, and thickness in the same field, and different fields divulge an immense variety of sands. Some sands are so fine as to be almost indistinguishable from clay, and when moulded in the fingers in a damp state impart the soapy sensation associated with clay. These sands often alternate with clays, and graduate by imperceptible changes into a true clay; others form a succession of thin laminæ where each alternation is visible.

Extremely fine sands are sometimes productive of oil, but in many fields yield either gas alone, or gas with such a small quantity of oil that they cannot be commercially developed. In the Baku oil-fields of Russia the finest sands yielded as a rule only gas, and were passed in drilling as unproductive, but persistent bailing in these sands often led to the entry of coarser oil sands, probably lateral extensions of these finer sediments.

The Surakhany gas sands were mere dust in which had accumulated gas and a little light filtered oil, which was ejected as spray with the fiercely expelled gas.

Many supplies of oil are derived from medium to coarse consolidated and unconsolidated sands, having a porosity or void capacity of from 20-30 per cent. by volume. Sands of such consistency, if fairly continuous, both absorb and readily yield their oil contents, and unless converted into rock or compacted in some way, break down freely under the influence of gas and are raised with the oil. The sand raised with the oil from individual wells varies often in quality, proving that the source of supply is not confined to one grade of sand, but extends to sections where its character is different from that where first struck. The Russian and Roumanian fields of Europe, especially the former, are renowned for the immense quantities of sand raised with the oil, an amount which has necessitated the employment of a system of extraction nowhere else found necessary.

The exact porosity of sands is difficult to determine, and precise data might have little practical importance in view of the variable dimensions and differing proportion of the grains within short distances. Perfect spheres of equal diameter will give maximum and minimum void capacities of 47.64 and 25.95 per cent. according to the grouping of the particles. Some sandstones have a capacity as high as 38 per cent. Volumetric capacities of 30-35 per cent. are common in sands[2] from which water supplies are obtained[1]. Useful experiments have been made by Charles Moore on the porosity of rocks, which quite confirm the observations of others, although his method of estimation by drying in a vacuum may have differed.[3] Porosities of from 24-30 per cent. by volume were observed in many sandstones of British origin.

Most oil sands are composed of a mixture of small and large grains of irregular shape that must detract from volumetric

[1] Nineteenth Annual Report, United States Geological Survey, Part II.

[2] "Motion of Underground Water," C. F. Slichter, United States Geological Survey.

[3] "The Study of the Volume Composition of Rocks," Charles Moore, *Proceedings Liverpool Geological Society*, 1901-2.

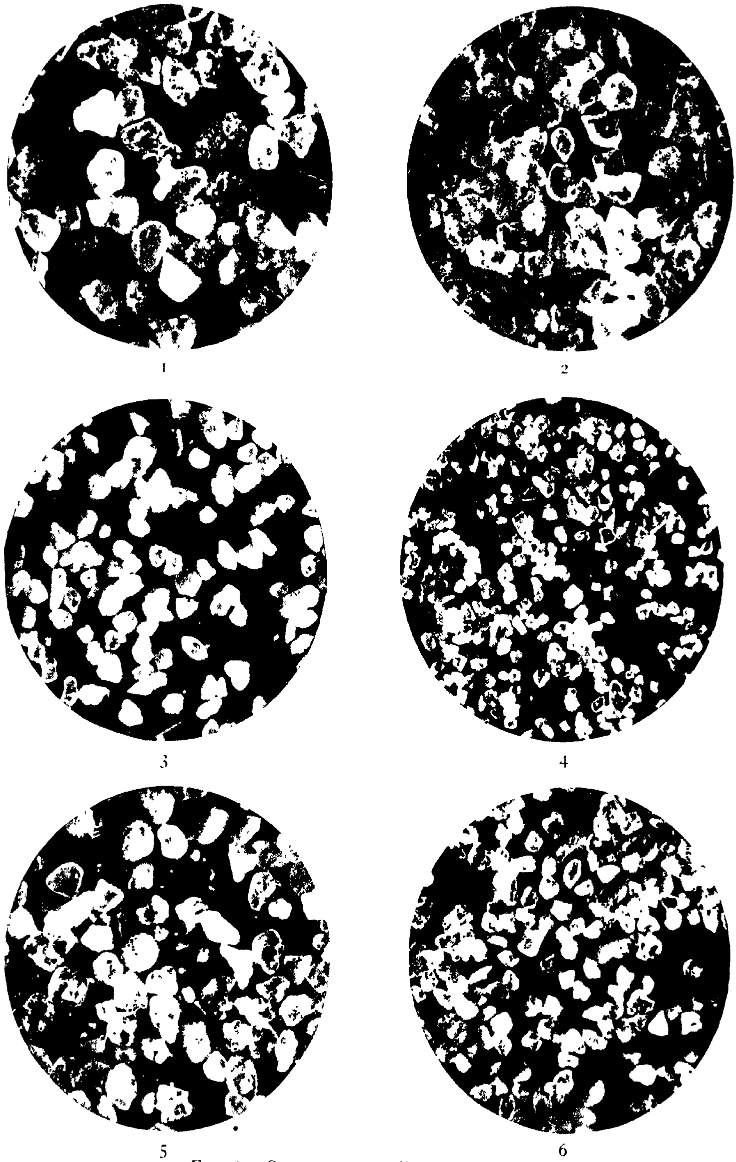


FIG. 6.—SCREENED OIL SANDS (RUSSIAN).

(Sample 1.)

1. Retained by 80-mesh screen.
2. Retained by 100-mesh screen.
3. Retained by 150-mesh screen.
4. Retained by 200-mesh screen.

(Sample 2.)

5. Retained by 100-mesh screen. (Note foraminifera.)
6. Retained by 150-mesh screen.

Magnification, 16½ diameters.

[*To face page* 106.

capacities approaching those reached by regular spheres. Some experiments were undertaken, at the instigation of the author, to determine the relative proportions of grains that would pass various sized screens up to 200 meshes per inch, beyond which the screens are unreliable. Much difficulty was experienced in cleansing the particles of oil to effect their absolute separation. The results suggest a direction for useful study, and particularly disclosed the wide variation in average size of particles within the same field. Appended are the results of a few Russian oil sands.

RESULTS OF SCREENING RUSSIAN OIL SANDS.

Size of Screen.	Percentage by Weight Detained by Screen.				
	Sample 1.	Sample 2.	Sample 3.	Sample 4.	Sample 5.
20 meshes to inch	...	...	...	...	...
40 " "	...	...	...	...	...
60 " "	...	...	...	...	...
80 " "	...	1.6	...	...	...
100 " "	...	4.9	...	5.2	...
150 " "	6.9	29.6	...	24.7	0.2
200 " "	19.7	38.1	...	31.4	19.1
Passed 200 meshes	73.4	25.8	100.0	38.7	80.7
	100.0	100.0	100.0	100.0	100.0

Provided oil sands can be cleansed of the last traces of oil without raising to high temperatures, there is little doubt that the elutriation process described and applied to metallurgy by H. Staddler[1] would prove useful for the separation of sand grains. By carefully adjusting the velocity of flow of water, fine grains of various grades can be isolated and collected in a way impossible by other methods. There is, however, the objection that density influences separation, and there might be cases where the particles varied sufficiently in specific gravity to diminish the value of this process.

The rich oil sands of medium grade have a very curious appearance when raised fresh from wells, and in Russia their

[1] "Grading Analysis by Elutriation," H. Staddler, *Trans. Inst. Mining Metallurgy*, 1913.

close resemblance to fresh caviare has led to their denomination as "caviare" sands when especially rich. The particles of sand are so enclosed in a film of oil and loosened by occluded gas that they have the above described appearance, and for a time behave like a fluid rather than a sand.

The normal oil sands often contain nodules varying in size from an inch or two in diameter to a foot or more across. The nodules are always well rounded, and generally spherical or oval but sometimes more fantastic forms are developed. The formation of nodules is not well understood, and their origin is of purely academic interest, but it is useful to record the fact as indicating the suitability of oil sands for their formation. Whilst some nodules are obviously concretionary in structure, others are not, as they reveal stratification when split, and when exposed to the atmosphere fracture along parallel planes.

A nodule illustrated in Fig. 7, Plate IX., has a carbonaceous nucleus, and this kind is very common in the Baku oil-fields, where tons of them varying from 1-12 in. in diameter have been raised from single wells or ejected during the gushing period. These sandy nodules are always calcareous, the sand grains being cemented together by carbonate of lime. In sections of the oil-bearing series of strata in Roumania, Burma, Peru, and California, nodules may be seen standing out in bold relief, having resisted weathering longer than the sands in which they are embedded.

The enormous quantities of sand which are extracted with the oil in the Baku oil-fields of Russia cause an accumulation of nodules around the base of the well towards which the sand and oil flow prior to extraction, and when wells are deepened or cleaned, or where new wells sunk near old producers reach the same source, several tons of collected nodules have often been raised.

Quantities of mechanically formed nodules have been collected from some wells, and they should not be confused with true nodules. Under the influence of large volumes of gas the sand in the well is kept in constant agitation, and any particles of rock which become detached and mix with the sand have their angular portions broken off, and they are gradually given a spherical shape.

PLATE IX.

FIG. 7. NODULE OF CALCAREOUS SANDSTONE WITH CARBONACEOUS NUCLEUS, FROM BAKU OIL-FIELDS OF RUSSIA.

FIG. 8. HOLLOW CONCRETIONARY NODULE FOUND IN PERUVIAN OIL-FIELDS.

[*To face page* 108.

A curious kind of hollow concretionary nodule found in the Peruvian oil-field is illustrated in Fig. 8, Plate IX.

Lateral variation is not restricted to change in grade of sand or thickness of strata, for another feature has been observed which has far-reaching influence on the distribution of oil in some fields. Within short distances, loose or slightly indurated sands saturated with oil change into hard calcareous sandstones, sometimes dry and at other times containing petroleum. The difference is due to the cementation of the sand particles by lime or silica, causing often an exceedingly hard rock, through which drilling is quite difficult.

Below are appended two analyses of calcareous sandstones taken from Baku oil wells :—

	Per Cent.	Per Cent.
Sand	53.49	63.164
Calcium carbonate	41.81	30.627
Soluble silica	0.20	...
Iron, Fe_2O_3, etc. (phosphates)	0.28	2.542
Calcium sulphate	0.19	0.580
Magnesium carbonate	1.78	1.510
Sodium chloride	0.12	0.247
Bitumen, sulphur and loss	2.13	...
Calcium phosphate	...	0.306
Sodium carbonate ?	...	1.436
	100.00	100.412

The cause for the change within short distances has given rise to speculations as to whether the original stratum was all cemented by carbonate of lime, and part subsequently removed by dissolution in patches, or whether lime carbonate was deposited at a later date, or the bed contained sufficient carbonate of lime in parts to form a cement. Reference was made by the author to this peculiarity and its effect upon the production of wells in a paper to the Petroleum Congress at Bucharest in 1907,[1] and since then several writers have referred to this feature and recognised its importance. As far back as 1902

[1] "Notes on the Irregular Distribution of Petroleum," Third International Petroleum Congress, Bucharest, 1907.

W. T. Griswold,[1] in his report upon the eastern Ohio oil-fields for the United States Geological Survey, stated: "In many instances, within a distance of 600 ft. from wells of large production from a good sand, other test wells have found the sand hard and closely cemented, and incapable of holding fluids of any description."

Baku operators were long ago aware of the presence of calcareous boulders more or less impregnated with oil, and drillers often had their wells thrown out of vertical by the drilling bits striking the edge of a hard mass. Wells sunk in areas where certain sands showed great regularity, occasionally penetrated hard calcareous sandstones at the depth where loose sands were anticipated. When pierced these sandstones never gave a phenomenal yield, but often produced steadily for many years without any of the difficulties and dangers that surrounded those wells sunk in loose sands near by. The raised oil was contaminated with little sand, and it apparently issued from fissures in the rock, as the sandstone appeared too compact to allow of the passage through its pores of quantities of between 15 and 60 tons (110-450 barrels) daily.

Pascoe[2] attributes irregular distribution of petroleum in the Pegu series of Upper Burma largely to erratic impregnation of the sands within an oil horizon with carbonate of lime. He asserts that neither faults nor lenticularity will adequately explain the difference of strata in wells in close proximity. It has also been noted in Burma that the volume of oil in the sandstones bears a rough relationship to the percentage of lime in the sandstones; and examinations of outcropping oil sands in the Yenangyat oil-fields confirm this statement. A. W. Bleeck informed the author that in the Pokokku district of Burma he followed an outcropping oil sand for several miles, and found that oil seepages were mainly confined to friable sands containing little lime. Where the beds were harder, and contained a high percentage of carbonate of lime, there were no seepages; consequently, the oil-bearing capacity of a horizon appeared largely influenced by the degree of cementation.

1 "Contributions to Economic Geology, 1902," p. 37, United States Geological Survey, Bulletin 213.

2 *Memoirs of Geological Survey of India*, Vol. XL., Part I., 1912.

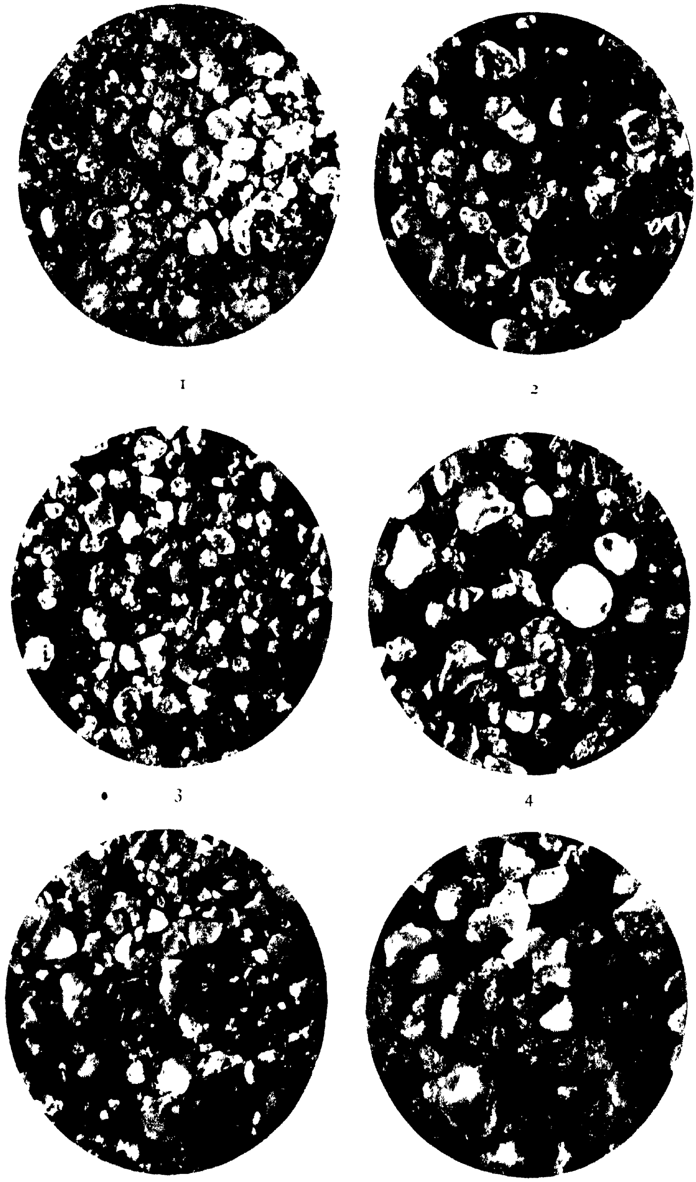


FIG. 9.—VARIOUS OIL SANDS.

1, 2. Baku, Russia. 3, 4. Maikop, Russia.
5. McKittrick Oil-Field, Kern Co., California. 6. Peru (Negritos).

Magnification, 17 diameters.

[To face page 110.

Peru presents many fine examples of the influence of calcareous impregnation. The author traced, in a hillside section, an exposure where a thick, richly-saturated oil sand suddenly changed into an almost flint-like calcareous sandstone absolutely barren of oil. The erratic yields of wells penetrating the same source are largely accounted for by this variation in composition of the oil-bearing stratum.

With the exception of California and parts of Texas, American oils of an arenaceous origin are mainly confined to consolidated or cemented sands, many of which only yield up their oil contents when subjected to considerable concussion by blasting with high power explosives. Enclosed petroleum lies stored either in irregular or discontinuous lenticles throughout the main mass, or in slip and joint planes which, until adequately disturbed, do not allow the contained fluids to issue. Sometimes little or no manifestations of oil are noted where the anticipated sand has been penetrated by drilling: at other times only insignificant yields are obtained till a powerful torpedo is fired to fracture the stratum. Wells are rejuvenated by repeating the process of blasting at intervals when the supply of oil decreases (see Chap. VII.).

Other fairly calcareous sands, like the "hundred foot" of the lower Carboniferous of the Appalachian oil-fields—a stratum which has been traced over thousands of square miles—only yield oil in certain localities, but even within those areas of concentration oil is confined to certain soft patches or pay streaks of extremely varying dimensions. The productive lenticles are often coarser sands, conglomeratic in nature, and far more porous than the surrounding sandstone, which is itself of medium coarse grain and porosity.[1]

When oil sands do not disintegrate with the extraction of oil, it is natural to anticipate a much lower rate of yield than from sands which break down, and so permit the expulsion of their contents.

Sands and sandstones displaying no calcareous cementation are often impregnated in an irregular manner which is difficult to explain. Sections of thick sands in the Guapo District of

[1] "Study on the Application of Anticlinal Theory of Oil and Gas Accumulation," Malcolm Munn, *Economic Geology*.

Trinidad show dark coloured areas of dense impregnation, and light patches of almost unstained sand. The areas of saturation and discoloration bear no relationship to stratification, yet it is difficult to conceive of circumstances which would prevent the passage of oil throughout their mass were a well sunk in the vicinity of a rich patch containing oil.

Plates X., XI., and XII. illustrate a number of representative oil sands from various oil-fields. Their compositions, though essentially silica, vary greatly, and their capacities likewise show wide differences. The figures prove that oil is confined to no one class of sand, and quite disprove the common impression that certain kinds of sands are water sands, others gas-bearing, and again others oil-bearing. In an oil series any sand may produce oil, but usually remunerative yields are restricted to sands at certain horizons which become known by experience. The productive sands in some regions possess characteristics which become associated with oil by local drillers, and they often, without adequate justification, apply a distinction which leads to grave subsequent mistakes.

Within definite areas sands of a certain grade of grain and of more or less continuity may be water-bearing or barren, but deeper or extended drilling may disclose sands of the presumed water grade type productive of oil. Until a field is very well understood it is presumptive to attach to any kind of sand any indication of its contents. Some pure siliceous sands which carry light oils are washed white and clean by admixture with water, such as is always used during drilling, and any temptation to disregard their presence and make no test for oil should be resisted.

Some sands tenaciously retain their discoloration, and disclose their rich character. This especially applies to heavy asphaltic oil-bearing sands, which do not lose their black tint even when washed up in a rotary plant from a depth of 2,000 ft. or more. Even light oils often cling so pertinaciously to the particles of sand that fragments clinging to the drilling tools can be raised through a deep column of water without losing their brown discoloration and oily aspect.

PLATE XI.

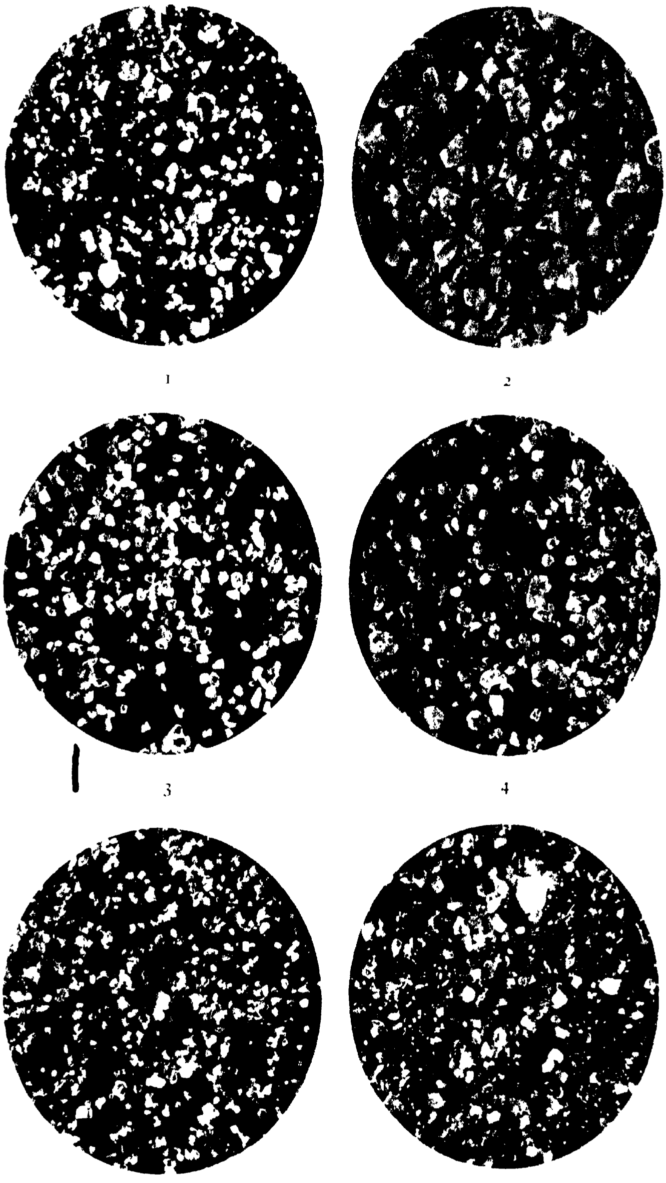


FIG. 10.—VARIOUS OIL SANDS.

1, 2, 3, 4. Trinidad, West Indies. 5. Beciu, Roumania. 6. Baicoi, Roumania.

Magnification, 17 diameters.

[*To face page* 112.

Petroleum is often thought to exist in subterranean caverns, which it is the aim of oil operators to locate and pierce. This erroneous impression arises from the lack of appreciation of the porosity of arenaceous and calcareous rocks. In some cases, to which reference is made on p. 126, limited supplies of petroleum have accumulated in favourable localities, but the sole normal reservoirs for oil are porous strata. The immense volume of water withdrawn from certain sands, or expelled under hydrostatic pressure in artesian basins, should alone dispel doubts concerning the capacity of porous strata.

Several factors may have contributed to a porosity of oil sands beyond that based on their maximum capacity estimated from normal voids. If oil has been formed from organic material deposited with the sands, and this material has wholly or partially been decomposed or converted into oil, an additional space has been provided equivalent to the reduction in volume of the original material, neglecting reservations for diminished bulk by overhead pressure. That such has happened in some cases seems highly probable, especially where heavy asphaltic oils are found, whose viscosity discredits the view of long distance travel.

Sands, it may fairly be assumed, were mostly deposited in water, and in this way they pack naturally, presenting the most compact mass, and consequently containing the least voids possible and minimum capacity. If the sands in any way become disturbed by crushing pressure, the voids in the sands increase and the capacity for fluids increases. It is, therefore, possible that the severe crushing forces to which many oil-bearing series have been subjected during earth movements may have imparted to the sands capacities much beyond their original ones.

This little known property of sand, to which no reference has hitherto been made in petroleum literature, so far as the author is aware, may be seen every day on a seashore. When walking along a sandy beach near the sea, each footstep causes a dry patch to form as one's weight is thrown on the sand. This is due to the compression and disturbance of sand saturated with water, the pressure upsetting natural packing and increasing the voids in the sand, and hence its capacity, instead of decreasing its holding power.

On the other hand, sandstones in proximity to a fault display diminished void capacity. Charles Moore has shown this effect of compression on rock capacity in a number of cases. Referring to a Keuper sandstone, whose normal porosity was 22.5 per cent., he shows that the porosity gradually and uniformly fell as a fault was approached, to as low as 16.50 within 3 in.; on the other side of the fault the Bunter showed a porosity of 14.80 per cent. at 3 in., 15.50 per cent. at 12 in., 22.50 per cent. at 2 ft., and its normal of 25.50 per cent. at 12 ft. The specific gravity and composition of the rocks remained practically the same.

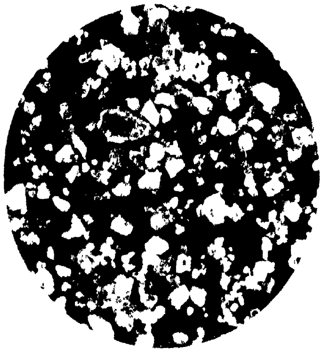
The coarsest oil sands illustrated are capable of absorbing from 20-30 per cent. of their volume of fluid. The capacity of a sand with 20 per cent. voids is 8,700 cub. ft. per foot-acre, or 1,550 barrels (207 tons) of oil per foot-acre. A bed of sand 50 ft. thick would, therefore, be capable of holding in its pores about 75,000 barrels equal to 10,000 tons of .850 gravity oil per acre.

Gas must naturally occupy space, and where the gas is mainly methane it is necessary to regard the bulk as occurring in a gaseous state, as it is only liquid at temperatures and pressures which do not exist in any operated oil-field. If 500 cub. ft. of uncondensible gas at atmospheric pressure are yielded per ton of oil extracted, and an average earth pressure of 500 lbs. per square inch is allowed, neglecting temperature corrections and partial solution of gas, the undermentioned bulk of gas would reduce the volume of oil contents proportionately. The volume of gas under the assumed conditions would be about 3,000 cub. ft. per foot-acre, leaving a capacity of $8{,}700 - 3{,}000 = 5{,}700$ cub. ft. for oil, equal to $\frac{5700}{42} = 135$ tons (about 1,000 barrels) of .850 density oil per foot-acre. It must be understood that the above calculations are purely approximate to arrive at a rough idea of subterranean absorptions.

The richest oil-fields of the world, in Russia, have yielded in round figures perhaps as much as 350,000 barrels per acre spread over the total developed area of the field. Where such large quantities have been abstracted there were numerous productive sands at intervals through a vertical thickness of about 2,000 ft.;

PLATE XII.

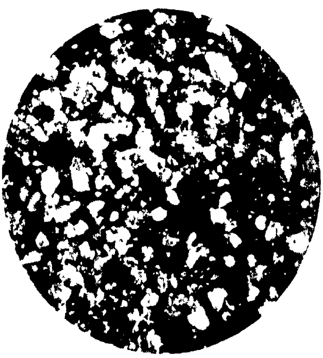
1



2

3

4



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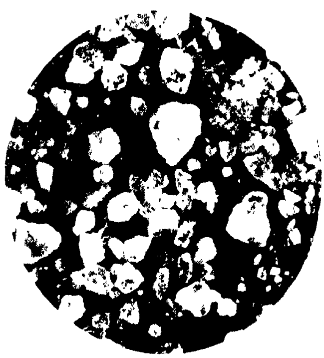

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FIG. 11.—ROUMANIAN OIL SANDS.

1. Moreni (Bana). 2. Moreni (Bana) Dry Sand. 3. Gropi.
4. Moreni (Stavropoleos). 5. Tintea. 6. Chiciura.

Magnification, 17 diameters.

Face page 114.

the formation of dolomite. Dolomite is a double carbonate of lime and magnesia, and is the result of a curious recrystallisation of certain limestones under definite conditions, that cause the total obliteration of original fossils or structure. At pressures between one and five atmospheres, water containing carbonic acid will dissolve both calcium and magnesium carbonate, and under saturated conditions the double carbonate is deposited. The change from calcite to dolomite involves a shrinkage of volume of about $\frac{1}{11}$ of the original mass.[1] Such a porous stratum would naturally constitute an ideal receptacle for oil, were it to be favourably located, and it would naturally facilitate the rapid expulsion of oil were relief afforded after it had been confined under high gas pressure, if the vesicular parts communicated.

Normal dolomite contains 45.65 per cent. of magnesium carbonate, but signs of dolomitisation have been observed where the proportion of magnesium carbonate did not exceed 10.15 per cent.

Common limestones do occasionally contain oil, and some bituminous limestones are largely employed for street paving purposes after some little treatment, but the latter rarely yield oil in quantity. Throughout a wide region in Portugal bituminous matter fills innumerable slip planes and interstices in limestones.

The oil-bearing dolomites of Canada, which now yield only small supplies of oil resembling that of Ohio, are similar to those of the later region. A typical example taken from a Canadian well near Petrolea is illustrated in Plate XIII., No. 3. This sample is discoloured, and is sufficiently vesicular to give a far greater absorptive capacity than 20 per cent.

Spindle Top, Texas, owed its fame to the existence of a dolomitised limestone containing a preponderance of calcium carbonate. Messrs Hayes and Kennedy[2] give the following information concerning the nature of the oil-bearing dolomites of this wonderful pool: "Pieces of the stratum expelled from wells during the gushing period showed that the dolomite contained numerous cavities as much as an inch in diameter, and there was

[1] See Professor Skeat's paper, *Geological Society's Journal*, Vol. XII., February 1905.

[2] Report, Geological Survey, United States, 1903.

PLATE XIII

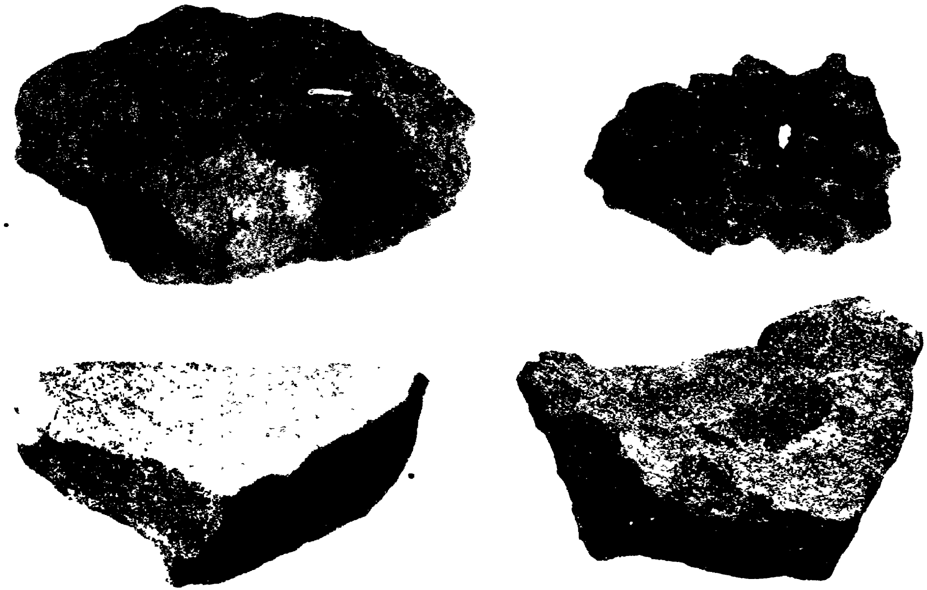

FIG. 12.—TYPICAL OIL SANDS AND DOLOMITE

1. Fine grained, richly impregnated Oil Sand.
2. Rich Oil Sand from Outcrop. (The upper surface shows the bleached and disguised appearance as a result of prolonged exposure to atmospheric conditions.)
3. Oil-bearing Dolomitic Limestone. (Removed from a Canadian oil well.)
4. Coarse-grained Oil Sand charged with Heavy Oil.

[*To face page* 116.

reason to believe that cavities measured in feet occurred also. The cavities were lined with a layer of crystalline calcite, the free ends extending into the open spaces. Although no definite determination could be made of the relative volume of the open spaces, it was considered that the rock must have been able to contain at least one-third of its volume of oil. Such an exceptional porosity accounts for the extremely prolific character of the pool, and its rapid exhaustion, both of which points have been the source of considerable speculation."

Foster Bain[1] gives the following interesting analyses of limestones in the Illinois oil-field, taken from various points in an oil-bearing formation. The analyses indicate the dolomitic character of the most productive oil horizon.

	Above Best Pay. 361-365 ft.	In Best Pay. 380-385 ft.	Below Best Pay. 395-400 ft.
Calcium carbonate ($CaCO_3$)	46.38	51.38	55.16
Magnesium carbonate ($MgCO_3$)	20.69	28.76	17.64
Iron oxide and alumina (Al_2O_3, Fe_2O_3)	10.93	3.71	2.47
Insoluble	21.69	11.45	24.47
Total	99.69	95.30	99.74

Migration of Petroleum.—The migratory habits of petroleum, to which an allusion has been made when discussing the anticlinal theory, present many phenomena of a perplexing character when complex geological structures are concerned. Some strata under all the geological changes of pressure and flexure have preserved their plastic nature, and submitted without fracture to irresistible thrusts which have imparted fantastic and involved contortions without allowing the escape of their oil contents. Strata which have suffered only gentle folding have generally retained their original oil, although in a concentrated degree at certain points; but where beds of a fragile nature have been given intricate folds, petroleum and natural gas have sometimes migrated into overlying or neighbouring series of strata which originally contained no oil or gas.

[1] "Petroleum Fields of Illinois, 1907," by H. Foster Bain, U.S. Geological Survey.

The anticlinal theory has become such an accepted axiom of petroleum mining that any opposing dips, local flexures, or surface deformations, which could be remotely construed as an anticline, have often been given a significance quite out of proportion to their value, when more valuable structures alongside remained neglected. Many oil-fields of great commercial importance present structures which could only be described as anticlines by a very wide stretch of imagination, and there are numerous regions where monoclines, successions of creases, and even synclines are productive of petroleum. Examples are given elsewhere of typical oil-field structures illustrating varied features.

The ideas introduced under the word migration are of two kinds: Firstly, the more or less local movements of oil within the limits of the formation in which it is found, largely summed up in the anticlinal theory with some modifications now to be discussed, the general trend of which will not receive active opposition; secondly, that view of the movement of hydrocarbons in the earth's crust which supposes them capable of traversing considerable thicknesses of beds, and regards them as not necessarily having originated in or near the formation they now occupy. This latter type of migration, often called regional, is one about which little direct evidence is forthcoming: it furthermore is very actively opposed by many competent authorities. Nevertheless, it is irrational to deny to gaseous and liquid hydrocarbons freedom of motion which is granted to water or aqueous solutions.

The readiness with which oil enters porous strata, and permeates large areas when the porous beds are impregnated with water, has been illustrated in several oil-fields where the rich deep sands have been brought into contact with shallow beds. The surface yellow sands of the Baku oil-fields, which formerly contained water, were later the object of a flourishing industry created by peasants who sunk pits and extracted oil in pails or skins. Petroleum has entered and saturated raised beaches of recent date in Trinidad, and in the Apsheron Peninsula horizontal post-Pliocene beds are impregnated with oil from inclined oil-bearing strata that unconformably underlie them.

A bed of gravel, from which the farmers obtained their supplies of water, covers the rich eastern part of the Campina oil-field of

Roumania. Large flowing wells on this plateau led to the impregnation of the gravels with oil that was transported from point to point by water. For miles around the peasants extracted oil where formerly they drew water, and on the hill side where the plateau is cut into by the River Doftana, oil may be seen exuding from the gravels.

Faulting or damaged casing in an oil well will permit upper exhausted or barren oil sands, or even drained water sands, to be replenished when oil is flowing fiercely from a deeper source.

Acute flexuring in all but very plastic strata must be attended by considerable dislocation, and such faulting permits of a wider distribution of petroleum and gas than originally prevailed if the essential conditions exist. A suitable series of strata overlying an oil-bearing series, perhaps deposited upon the former after flexuring had proceeded for some time, and consequently less inflected and disturbed, might form a suitable medium for the escaping contents of the lower beds. The contents of oil-bearing strata of a resisting nature, that had suffered faulting after subjection to severe stresses, might be expelled into more plastic, porous, yielding beds which could absorb any fluids.

There is abundant evidence of migration in oil-fields where the oil is still confined to the oil series, although concentrated mainly within certain vertical limits where protection is afforded from loss due to distance from surface, and so permits remunerative drilling to be performed. Beyond certain depths the oil series either ceases or water-bearing sands are struck, sands which at one time were probably oil-bearing, but from which oil was subsequently expelled by water.

Gravity naturally plays an increasingly important part in the movement, interchange, separation, and concentration of water and oil as the declivity of the flanks of an anticline increase. Proof of the migration of oil is manifested in a variety of ways. Along the crests of denuded or faulted anticlines, issues of gas and seepages of petroleum, or a mixture of petroleum and water, are of great frequency. Even along protected anticlinal crests, oil, gas, or both often escape from points of weakness. When folds deviate slightly in their main direction, such issues are generally particularly pronounced owing to fracturing, and

such areas of special activity lead one, in the absence of surface evidence, to suspect some change of strike.

For untold ages gas and oil have incessantly or intermittently been expelled from oil and gas bearing strata extending for miles along most of the great oil-bearing belts of the world, and at periods of seismic activity violent discharges have occurred, some of which are described more fully in the sections dealing with indications of oil (pp. 178-79). It is asserted, though not confirmed by reliable and methodical observation, that variations of atmospheric pressure, seasonal rains, rise and fall of tides, and age of moon, have influence on the degree of activity of natural exudations. Such is quite likely, as equilibrium is established as a result of the balancing of forces which under certain conditions could conceivably be modified by some of the above factors.

The main point, however, is that there are constant movements of fluids in the earth at times when there are no earth vibrations to disturb these fluids. Further, it is apparent that these movements must be extensive and far-reaching, to provide for the losses by dissipation that have proceeded for ages, and must often in the aggregate far exceed in volume the material subsequently derived as a result of the operations of man. In this connection it is interesting to note that the oil-fields of older geological age, from which the lighter density oils of the United States have been mainly obtained, have suffered little flexuring, and practically no loss by dissipation, and could thus represent the concentration of very sparsely distributed oil from a wide area. The elevated temperatures as a consequence of depth would further aid movements by reduction of viscosity. The immensely richer accumulations of many Tertiary oil-fields, often located on sharp inflections, probably represent the concentration and more complete displacement from much less restricted areas, promoted and accelerated by the greater inclination of the strata.

Evidence that the escape of oil and gas from outcropping strata is not directly attributable to displacement by accumulations of water in synclines is furnished by the fact that exudations continue, though on a diminishing scale, when beds further removed from the outcrop have been largely exhausted of oil and water by numerous wells. It is possible, perhaps, to

magnify the significance of this feature as evidence of subterranean movements, as prolonged escape of gas or oil from an area leads to the formation of definite channels along lines of weakness, which continue to afford outlet for gas that expands as it approaches the surface after release from a deep-seated source.

Time may possibly be able to achieve much that seems impossible when viewed from a commonplace scientific aspect. The rocks we regard as impervious are not so in reality, and time again may effect changes in their porosity and chemical composition. There seems little doubt that as slight elevations of level of sands in some of the American regions so frequently correspond with oil-productive areas, that with these movements must be associated the concentration of oil; but although elevated points are sought and often traced and tested, strata elsewhere productive of oil do not invariably disclose pools of oil. Sometimes the sands are dry, at other times only gas is found, and no adequate reason can be advanced for this difference.

Such slight departures from the horizontal lead one to cast doubts upon lateral movements of fluids being the sole cause of concentration at certain points. Any views regarding affinity of certain sands for oil may be dismissed in this connection, as distances introduce inadmissible frictional resistances, and one naturally leans towards theories in which vertical movements are involved. As these elevations are the results of earth movements, it is conceivable that under certain circumstances areas which yielded to these forces might fracture, and through such fractured regions fluids might be admitted to a porous sand within a certain range that elsewhere was dry or water-bearing.

The concentration of petroleum under the above-named geological conditions is rendered more difficult to imagine because the sands in which it occurs are often compact masses scarcely disintegrating at all when yielding oil, from which productions are usually only obtained by fracturing the rock by powerful explosives. It is also difficult to assert positively in all cases whether hydrocarbons saturate certain portions of these sands, or occur in fissures throughout their mass. The conditions are in any case such as to impose considerable opposition to migration. Gravity alone could do very little in assisting a lateral movement,

when inclinations of a few degrees only were involved, against viscosity in the oil itself and adhesion of the oil and sand. If, however, a movement were initiated through reduction of pressure at points of maximum elevation, occluded fluids would move towards such areas, and whilst water might escape to the surface or be absorbed in upper strata, oil would tenaciously cling to certain sands and gradually replace their original water or mixed contents. Excess gas pressures might be dissipated gradually with the water, in partial solution, or at intervals during earth movements, such as are probable at periods of uplift, of which we have no data to-day.

The dome structures of the Texas and Louisianian oil-fields furnish evidence of the transport and deposition of mineral matter, around which has accumulated oil. Is it not more likely that the oil has been transported from a distance by the water, than that its accumulation is due to concentration as a result of slight and local inclination in the strata? Capillarity, evaporation, and water of crystallisation would account for the diminution of the water, and concentration of petroleum in the porous beds would in time restrict the movement of mineral-carrying water, by introducing frictional elements of no small moment.

It is useless to try to disguise the fact that a scientific explanation of the lateral movement, and concentration of petroleum in slightly inclined strata is wanting. That concentration coincides with slight elevations of level is incontrovertible, and laudable efforts have been made to explain this. Mr Washburne[1] has collected a series of valuable data connected with the powers of capillarity providing food for reflection, but which leaves one nevertheless confused. This writer observes that since water has a surface tension of about three times that of crude oil, capillary attraction exerts about three times the force on water that it does on oil. As the force of capillarity varies inversely as the diameter of a pore, it is contended that this force tends to draw water into the finest tubes in preference to oil, and displaces contained oil and gas: the result being that oil would be expelled from fine-grained material like clays into coarse-grained beds like sand.

[1] "The Capillary Concentration of Oil and Gas," C. W. Washburne, *Bulletin of the American Institute of Mining Engineers*, September 1914.

Constant action of capillarity would, assuming the above action to continue, result in the displacement of oil from the pores of fine-grained beds, and its concentration in fissures, slip planes, etc., where sands were non-existent. Absence of water would prevent this movement, as any oil distributed amidst the beds would remain undisturbed. It is admitted that capillary force would be weakened by mixtures of oil and water (emulsions), and that bubbles of oil and gas would increase resistance considerably.

The small particles of oil, which would by this means be forced into the coarse sands or fissures, may then subsequently be collected to form larger accumulations by means of slowly moving currents of water, a very important rôle being played by the gas, a gas bubble always tending to pick up a pellicle of oil.[1]

The tenacity with which petroleum clings to some oil sands will be appreciated by anyone who attempts to free sands of oil for microscopic examination.

It is possible that the selective action is of water rather than oil in certain cases. If water of sedimentation, or otherwise, were in danger of displacement by intrusion of oil, certain patches of sand of, say, an acid character might display greater tenacity for water than others through the water adhering more firmly to the quartz grains. Other portions containing metallic sulphides might resist wetting by water, and would attract oil in preference. Such phenomena form the basis of the mineral separation flotation processes. Certain portions of sands possessing affinity for water would in this way retain water, whilst others became saturated with oil, the former eventually acquiring a pressure due to the sub-capillary pore water of surrounding shales. An upper layer of sand might, in this way, yield a negligible amount of water and oil, when the lower would prove prolific of oil.

Lenticles of more acid sandstones might, similarly, retain water in a mass of more neutral or basic sand, and resist tendencies to displacement by oil. Such sand might appear "dry" to the driller. Lenticles of this nature would form a convenient receptacle for the deposition of carbonate of lime, iron oxides, or sulphides that might arise from the action of oil or water, or both on surrounding country

[1] "The Accumulation of Oil and Gas in Sandstone," Roswell H. Johnson, *Science U.S.*, Vol. XXXV., 1912.

rock, as it is unnecessary to assume the lenticle saturated with water. Such action would result in the formation of concretionary masses or bodies of unequally distributed fluids.

George Madgwick has called attention to the sweating of oil from cretaceous white marls in the Maikop district, where only slightly impregnated with oil, when exposed to the atmosphere, giving them a dark external appearance. This he is inclined to attribute to the displacement of the oil by atmospheric moisture acting in the manner above described. The action ceases when enough oil has been ejected to form a coating against further access of moisture to the pores.

Some actual experiments have been recently carried out by Roswell H. Johnson,[1] in forcing a mixture of oil and water through a layer of fine sediment containing a coarse-grained lenticle of sand. It was found that oil accumulated in large quantities in the sand.

Light density oils, whose viscosity more nearly approaches to that of water, present fewer difficulties in explaining migration than those of the heavy asphaltic type that flow with difficulty, even in the presence of air and surface friction alone. It is inconceivable that such oils should have travelled any considerable distance in their present state, even allowing for diminished viscosity for elevated temperature; and certainly gravity alone would be impotent to impart movement in any but steeply inclined sands of great porosity, aided by gas. Nevertheless, Ralph Arnold submits striking evidence of the close association of the commercially unproductive Eocene (Tejon) beds with the prolific oil deposits of California, in the same way that Mrazec demonstrates the intimate connection of the unproductive Mediterranean (Salifère) with all the great oil-fields of Roumania. But whilst in Roumania involved, steeply inclined, and broken structures are typical of many of the great oil-fields, thus presenting simple opportunities for the migration of the light oils that characterise these fields, many of the greatest Californian oil-fields are represented by little inflected beds, with inclinations of only a few degrees, though perhaps resting unconformably on more inflected strata.

[1] "The Rôle and Fate of the Connate Water in Oil and Gas Sands," *Trans. Am. Inst. of Mining Engineers*, 1915.

Opponents of orthodox theories sarcastically remark upon the kindness of Nature in withholding the escape of contained oil in outcropping inclined strata until suitable beds have been deposited along their exposed edges to receive their contents. This latter criticism is perhaps not quite justified, as there are numerous oil-fields operated to-day in proximity to, or in the midst of seepages where oil and gas have been escaping for unknown ages without exhausting their fluid contents. The only intelligent explanation of such phenomena as California presents, if geologists have correctly interpreted the intimacy above alluded to, is that water under hydraulic pressure has carried with it oil from the mother series in its efforts to find an outlet, the oil particles in its path being detained by surface friction whilst the water continued on its way. It might be argued that the oils now found are merely a residue of lighter products, in which case one would expect to find more frequent indications of the lighter varieties; nevertheless, the contention is reasonable.

Commendable criticism of the anticlinal theory of oil accumulation is submitted by Malcolm J. Munn[1] in discussing the structural features of certain oil pools in Pennsylvania. Careful levelling of some 2,000 wells, spread over an area of about 226 sq. miles, confirms the main occurrence of petroleum pools along the crests and near flanks of anticlinal folds. The sand selected was that known as the "hundred foot," near the base of the Carboniferous, as this was readily detected and sufficiently continuous to cover the whole area under study. Dips of from 1 in 26 to 1 in 175 were revealed within the area of concentration, and it was observed that mixed oil and water impregnated only certain detached lenticles throughout the sand. The proportion of oil, water, and gas, or level of liquid bore no relationship to the position of the pay streak or to each other, but it was remarked that exhaustion of water corresponded with exhaustion of oil.

Special attention is directed by Munn to the impossibility of accepting gravitation as the operative force where dips of such insignificance occur, and when the maximum difference of specific gravity between the contained oil and water was 0.2646.

[1] "Studies of the Application of the Anticlinal Theory of Oil and Gas Accumulation" (*Economic Geology*).

In discussing the origin of oil in the Kern River oil-field of California, where the beds are notoriously lenticular and prolific in diatoms, Anderson remarks:—

"Naturally, in the sedimentation of any basin, the sandy detritus usually remains near shore and the fine materials are carried away to other localities to be deposited. Also if diatomical and other delicate organisms form any appreciable deposits they will more probably be formed off shore. In subsequent regional deformations of the strata the organic deposits are apt to be left occupying the position of synclinal depressions bounded by the sandy shore line deposits left lying in positions inclined toward the interior of the basin. If such organic deposits give rise to any supply of petroleum or other liquid or gaseous substances, these may be forced to migrate laterally along the bedding planes of the strata, and into the sandy strata of the border, far more readily than they could be forced upward through the clays and shales and into overlying beds.

"If deposits of petroleum are subsequently found in sandy shore deposits, we may expect to find not far away in the same beds the source and origin of it. Along the Kern River the conditions are all that could be required to support the view that lateral migration has been the means by which accumulation has taken place. The extent to which water, oil, and gas may migrate laterally along bedding planes in the process of geologic periods is, of course, very great; but the fact that it is retained at all in the rocks, even under enormous pressure, is very good proof that it cannot migrate in a vertical direction transverse to the bedding plane."

Distinct forces may thus be operative in inducing concentration under varied circumstances. Highly fractured, steeply inclined flexures would present little obstruction to migration, when gravitation could be given full scope. In slightly inclined strata, uncomplicated by unconformities, concentration might be induced by a process of partial water absorption from porous seams, and displacement of finely divided oil from clays to sands.

In this connection it is of interest to note the frequently recorded occurrence of bright blue clay as hanging wall or base of oil sands. Pascoe[1] calls attention to this feature in Burma and Assam, and suggests a genetic relationship to the oil. Similar blue clays were regarded as a clue to the proximity of an oil source by the old Roumanian shaft diggers, who selected this clay in which to sink their wells. Arnold[2] refers to the fine blue sandy shale, known to the drillers as the "big blue," in the Eastside Coalinga oil-field, where it immediately overlies the upper Vaqueros oil zone.

[1] *Memoirs, Geological Society, India*, "Oil-Fields of Burma, 1912."
[2] Bulletin 398, United States Geological Survey, "Coalinga District."

Eldridge[1] also notes the occurrence of blue clay above and below the oil sand of the Kern River district. A chemical investigation of these blue clays might prove of great interest; possibly they are phosphatic beds indicating, as is so often the case, the shallow water ending of a particular geological period.

A feature which discourages the assumption that considerable lateral or vertical movements of oil have occurred in undisturbed strata, is the absence of purification which usually ensues when oils are forced through fine sediments. That such purification does proceed in the earth is proved by the frequent occurrence of light-coloured and light-density oils in petroleum-bearing strata. Dehydrated, siliceous and aluminous minerals are commercially used in the practice of refining as decolorising media, and although when in a hydrated state, as in Nature, this effect is reduced, long passage through the sub-capillary pores of fine clays could not fail to bring about a refining such as few natural oils display.

The immense quantities of hydrocarbon gases and light oils (see p. 106) impregnating the fine sands overlying the main oil-bearing series of the Baku oil-fields at Surakhany, were doubtless derived from the deep-seated, normal, dark oils which were subsequently struck at much greater depths, of over 1,500 ft. in the same district.

In the occurrence of the solid bitumens, which fill fissures in clays in the vicinity of oil-fields, we have additional testimony of the absorptive and selective properties of clays (see p. 193).

Concentration in the great Tertiary light-oil fields, like those of Russia, Roumania, Galicia, Burma, appears to have been largely influenced by faults and slip planes, and not by a process of upward or lateral filtration through strata. All these fields give abundant evidence of faulting, even upon their nearly horizontal crests, and in Roumania it is the junction of the upturned and sheared-off beds and the thrust planes that are specially sought to secure the greatest yields of oil. There is little doubt that water was the agent of transportation and distribution, and that in many cases it was the medium that expelled oil from lower beds, and drove it into upper ones where, in comparative isolation, it could be suc-

[1] Bulletin 213, United States Geological Survey, "Contrib. Econ. Geology."

cessfully raised. The water is not often under hydraulic pressure, so consequently does not encroach upon oil-fields with the exhaustion of the sands.

After a certain stage has been reached, water may be the salvation of an oil-field (see p. 142), inflowing or infiltration water acting as a rinsing fluid, and washing out much of the remaining contents of the oil sands in its movement to points of extraction.

Although eminent authorities on petroleum mining have, in several cases, expressed unqualified conviction concerning the source of petroleum in certain fields where concentration has been attributed, not without excellent reasons, to migration, there are features that permit of no obvious explanation, and suggest caution in accepting such conclusions. Reference has already been made to the assertion that the oil of the Coalinga oil-field of California is derived from Eocene shales which the productive series unconformably overlie, and to the difficulties of fixing the forces instrumental in the transference and conveyance of such viscous products along nearly horizontal strata. The problem has been recently complicated by the discovery, first of lighter oils in the Eastside Coalinga field and then of paraffin-bearing oils at increased depths.

Roumanian developments in 1914 brought to light a similar inconsistency, where very pronounced views had been generally expressed concerning the Saliferous Miocene beds being the source of the oil of the great oil-fields in that country. Deep drilling in the Moreni (Bana) oil-field had disclosed the existence of deeper oil of a paraffin base in beds of Meotic age. In this case the same geological series yields paraffin-bearing oil at Filipeshti some four miles along the anticline to the east, but at Filipeshti the upper Levantine and Dacian beds that produce normal asphaltic oil at Moreni yield no oil, for the presumed and accepted reason that they are too far removed above the Salifère in the nearly symmetrical anticline of that field.

Both the above recent cases introduce elements of a disturbing nature. If oil is derived from the same source within the limits of the same field, there is the difficulty of reconciling the occurrence of an oil with a paraffin base in one series of beds and oil of an asphaltic base in another geological series. There

is no transition stage, and the disturbed condition of the Saliferous cores precludes recourse to explanations involving varying oil-forming conditions at various stages in the Salifère. It is difficult to conceive of any selective properties of certain oils for strata, or of strata for certain oils, and one is forced, therefore, to indulge in suspicions as to the common origin of the oil from the Salifère. Reference to p. 124, and Chapter V., will facilitate an understanding of the above.

Differences of density and varying percentages of contained hydrocarbons admit of explanations in numerous ways and, indeed, would rather be anticipated where migration had proceeded in numbers of distinct types of strata under profoundly different structural conditions, but differences in essential properties of oils, whose very origin is often attributed to a different cause, admit of no such simple explanation.

Problems of this nature are rendered more mysterious and inexplicable by the fact that in several of the Roumanian oil-fields beds of an identical age, within definite belts, present no agreement as regards their oil contents. At Moreni, Filipeshti, and Campina the Meotic beds yield true paraffin oils that are nearly solid at winter temperatures, although everywhere else in the country, even on the same anticline to the east, the Meotic series yield typical asphaltic oils when they recline against the Miocene Salifère.

This subject would be incomplete without reference to the Boryslav-Tustanowice oil-field of Galicia, which produces consistently to ascertained depths rich paraffin-bearing oils, besides considerable quantities of the solid ozokerite in the higher beds of certain parts of the field. Elsewhere in Galicia, oil-fields yield normal asphaltic oils, but areas are known, as also in Roumania, where seepages of paraffin oils or veins of ozokerite testify to the further existence of this grade of oil, although payable oil-fields have not been developed.

It is probably unwise to attach too much importance to the above inconsistencies, in view of the recognised ignorance of the true relationship of paraffin-base and asphaltic-base oils, but such conflicting results within narrow limits suggest caution in drawing sweeping deductions.

Causes of Pressure.—Petroleum does not flow from wells like

an artesian supply of water when fountains, gushers, or flowing wells are struck, but it is either expelled as a finely divided spray amidst great volumes of gas, or flows in spasmodic impulses through supersaturation with gas, in much the same way that air-lifts act on water. Volume of gas rather than pressure is the deciding factor in flowing wells; thus it is that wells of small diameter will continue to flow long after those of large diameter would have ceased. A small quantity of exceedingly high pressure gas would be less effective in inducing a natural flow than large quantities of low pressure gas, or even volatile fluids in the oil.

Unless petroleum is expelled with extreme violence—and in such cases the output generally partakes of the character of a spray—a misleading conception of pressure may be gained by casual observation: only closed pressures can indicate earth pressures. Unfortunately closed gas pressures have rarely been methodically recorded, except in gas areas where the gas is conserved and utilised for industrial purposes.

Pressures can rarely be measured in oil-fields such as some of the Russian and Roumanian, where great quantities of sand accompany the oil, and cut to fragments any object of obstruction; and in many oil-fields reluctance is felt by producers to check entirely flows of oil, as frequently reactivity on the old scale of yield cannot be excited. In other cases extreme danger attends endeavours to restrict violent flows, besides the incurring of heavy expenditure in special material.

Daily outputs of from 10,000-15,000 tons (75,000-100,000 barrels) of oil, accompanied by tens of millions of cubic feet of gas, and often as much sand as oil, are not simple to control, yet such wells have characterised initial development in a number of the great oil-fields of the world. Practically every oil-field furnishes abundant evidence of high gas pressures during its early development, and although actual pressures are not registered they are undoubtedly very high. Wells in Borneo, Oklahoma, Roumania, and Russia have been left for weeks, and even for a year in Borneo, blowing off gas before the pressure had been relieved sufficiently to permit the drillers to return and carry the wells to the deeper oil sources.

At one time oil-field pressures were generally attributed to a

hydrostatic head, and estimations based on levels of outcrops taken in the Appalachian oil-fields of the United States gave some basis for such assumptions. The hydrostatic theory is now discarded as untenable when applied to other oil-fields, and it is now known that pressures indicated by wells in the same field disclose such disparity, and occasionally such excessive pressures, that a hydrostatic origin is precluded from consideration.

Pressures as high as 1,500 lbs. per square inch have been recorded in West Virginia, where the wells are deep, but the more usual pressures vary from a few pounds to 500 lbs. per square inch. Closer investigation supports the view that pressures have often been overrated, and recent oil-field studies indicate that closed pressures are usually well within the limits of a hydrostatic pressure due to the depth of source measured from the level of water saturation. A depth of 1,000 ft. corresponds to a hydrostatic head of 432 lbs. per square inch, so that at 2,000 and 3,000 ft. respectively, pressures of 864 and 1,296 lbs. per square inch would result. If water were the controlling factor of pressure, consistency of pressures at constant depth below a certain datum would be anticipated, at least in the initial career of an oil-field, but no such constancy exists. If the static head of liquids in the well is taken as the indicator of pressure, some measure of comparison should be possible. Experience, however, shows that the levels of wells within the limits of a single field vary greatly, and no relationship can be established when presence or absence of water is allowed for. In the above figures fresh water has been taken as a basis of calculation.

The static heads of both water and oil, with due allowance for differences of density, do assume some regularity in some oil-fields within certain limits; and this head diminishes with the exhaustion of the field. Within circumscribed areas some fair consistency was noticeable in the steady lowering of static head in the Baku oil-fields as exhaustion proceeded, and it was especially observed that the water and oil acquired the same relative heads. Wells which turned from oil to water through imperfect exclusion or other causes indicated almost identical static heads.

Without the influence of gas, petroleum should obviously acquire a pressure equal to the hydrostatic head of capillary pore water,

but if gas continued to be generated in the process of oil formation, water should acquire the pressure created by the gas. The fact that pressures exceeding the natural hydrostatic head due to water would, in many cases, result in the gas finding means of escape by displacement of water or movements along faulted zones, is against the probability of petroleum usually occurring at a pressure far in excess of that possibly due to water.

The remote relationship of oil and gas pressures to hydrostatic head is illustrated in most oil-fields where water and oil are found impregnating different sands in the same series of strata, although erroneous deductions can easily be drawn from imperfectly studied phenomena. Flowing water may not be artesian in character, but due to the lightening effect of gas which gained access to the water source, or entered the bore hole from a gas source; likewise, high oil levels may not be true static heads, but accounted for by brisk evolution of gas. Discarding doubtful issues, it will still be found that water sources beneath and above oil sources give quite different static heads, and often far below those of the associated oil seams. In other cases, true artesian water flows are struck amidst oil beds having a much lower static head.

Malcolm Munn[1] has shown that the heads and volumes of water in the pay streaks of the "hundred foot" sand near the base of the Carboniferous series in certain parts of Pennsylvania neither bear nor have ever borne any definable relationship, and in recording the relative proportion of oil and water, he quotes a peculiar case in one pool where the quantity and head of the admitted salt water increases with the life of the wells, until oil is eventually excluded.

The most convincing proof that oil and gas pressures are in many cases not attributable to a hydrostatic head is the entire absence of any but the smallest traces of water in and around some oil-fields, and the fact that water does not as a rule encroach on the field as exhaustion of oil proceeds. Many oil-fields show exhaustion of oil and water with age, but in some fields something allied to synclinal water, or water under a hydraulic head, does appear.

[1] "Studies on the Application of the Anticlinal Theory of Oil and Gas Accumulation" (*Economic Geology*).

Oil pools in the Appalachian, Canadian, Roumanian (Bushtenari), Peruvian, and Russian (Balakhany and Maikop) oil-fields show declining, and in some cases almost total, exhaustion of petroleum without any influx of water such as would have followed its concentration under a hydrostatic pressure. In practically all the above cases referred to, depth of the oil sources assured a static head, if water existed, of sufficient moment to flood the areas involved.

The high pressures met with at the base of the syncline separating the eastside and westside oil-fields of Coalinga could not be accounted for by a hydrostatic head, nor would it explain the high pressures encountered in the syncline between certain folds in Trinidad.

Oil-field waters disclose chemical characteristics which often disclaim association with normal subterranean supplies. They present features which discourage migration ideas, and suggest their lifelong intimacy with the oil series from which the oil is still being extracted. Nevertheless, realising the extremely complicated structures and excessive faulting in many of the great oil-fields, it would be presumptuous to be too dogmatic about the influence of a hydrostatic head at some stage when internal circulation of fluids was not impeded by innumerable faults and involved flexures.

As explained more fully under migration, water has often been the medium of transportation and distribution of oil, and in some cases a hydraulic head has probably been partially responsible for the high pressures of oil isolated and held in position against impassable barriers, as in parts of Mexico.

The source of what might be termed the potential energy of petroleum is in reality hydrocarbons, some in a gaseous state, others in solution, but all capable of becoming kinetic and exerting great force when pressure is relieved. To methane must be mainly attributed the high pressures prevailing in oil-fields. Its close connection with oil through processes of migration, without separation, arouses the suspicion that its production continues, thus enhancing subterranean pressures within certain limits of pressure.

Assuming that the ideas put forward by the Engler school as to the process of conversion of fatty materials into petroleum

are correct, there is no difficulty in accounting for a large increase in methane during the later stages of the process, and probably after the sediments have taken up more or less their present position. Methane may continue to be evolved for considerable periods, and it is possible to imagine that after large quantities have passed into solution, both in the associated water and in the oil, the remaining portions may materially add to the pressure already existing in the oil and water.

When once subterranean equilibrium is disturbed by partial development of oil-fields, new forces commence to act that yield the phenomena described in the next section.

Subterranean Movements of Petroleum Occasioned by Development.—The exploitation of a rich oil-field must necessarily so upset equilibrium as to occasion some readjustment of subterranean conditions. Few persons intimately associated with oil-field operations have failed to come into contact with phenomena of the most puzzling character, affording to the unscientifically trained subjects for the wildest speculation. The sudden relief of millions of cubic feet of gas under pressures of 500-1,000 lbs. per square inch, and the ejection of 10,000-15,000 tons of oil daily, with sometimes an equal weight of sand, must bring about subterranean disturbances bearing upon the distribution of oil.

Practically all oil-containing strata are crushed and faulted where the structure is complex, and where hard resisting beds occur at intervals in the geological sequence. These fault and slip planes constitute lines of weakness that acquire increasing importance as development proceeds, as along these lines oil and gas travel to points of low resistance; their importance has been appreciated by observers in far-separated oil-fields, and their influence actually traced in some places.

Ralph Arnold directs attention to the important part played by joint cracks in the Californian oil-fields, and records his views in his report on the Santa Clara Valley, Puente Hills, and Los Angeles oil districts.[1] In Russia and Roumania faults and junction planes have been deliberately sought under the

[1] Bulletin No. 309, United States Geological Survey, p. 157.

conviction that their penetration at depth would lead to yields far beyond normal, and not in vain.

The development of the nearly horizontal, compact, and little faulted sands of many of the American oil-fields leads to no phenomena of note, as the maximum yield is at first, and production tails off as drainage ensues, until a shot is fired to break up the stratum further afield, and give the well renewed vigour. Not so with the more complicated, folded Tertiary oil-fields, especially where the sands are not compacted, and readily disintegrate, and travel with the petroleum they contain. The initial yield of oil is often small, and gas alone may be discharged for days, weeks, or even months before oil in quantity appears. The author has seen clean white sand violently expelled from Russian and Roumanian wells for many days before oil appeared, the whole country round being strewn with a covering whose weight caused the collapse of the roofs of buildings upon which it had fallen and accumulated. The sand becomes mingled with a gradually increasing spray of oil, until productions of several hundred tons, and sometimes several thousand tons daily are reached.

Expulsions of dry sand are not viewed with alarm, as they are frequently followed by oil, if struck within the limits of an oil-field. Provision is being naturally created for oil accumulation, by extending the influence of the well far beyond its immediate vicinity. The removal of much sand from wells, as generally occurs in the early stages of development of oil-fields where the oil is contained in loose sands, promotes the formation of an area of low density around the mouth of the lining tubes into which oil infiltrates and accumulates prior to its removal. For a long distance around the well the sand may, under the influence of agitation by gas, be impregnated to the extent of 50 per cent. of its volume, forming valuable receivers for the wells. From some of the richest areas in the Baku oil-fields as much as 20,000 tons of sand per acre have been ejected or raised with the oil.

The influence of early wells on an oil source extends much further than furnishing an area of high absorption and low

resistance, because as oil infiltrates into this area from lon distances it follows lines of least resistance along slip planes an coarser veins, thus producing in time definite channels deviatin in all directions, that act as feeders. Favourably located well unmolested by neighbouring operations till they are firml established, have an immense advantage. Later wells sunk i the vicinity do not derive the benefit of the high gas pressur which was responsible for the condition of the early well, an oil is not readily deflected into new channels, even when th sediment is unconsolidated, and especially when the sands ar compact, the resistance great, and an area of low destiny i absent.

The author has had this peculiarity many times thrust upo his notice when new wells have been sunk in the vicinity of ol producers in the Baku oil-fields, a new well within even 50 ft. (an old one, carried into the same sand at the identical deptl failing to produce more than a fraction of the then present yiel of an old well. An illustration of this feature was vividl impressed on the author's notice when opening up an old we that had for many years been abandoned as unproductive, wit the remarkable result that a production of 40 tons (300 barrel daily was obtained, and this in a district where the maximu initial yields of new wells sunk away from old wells was 15 tor (130 barrels) daily. Long standing had led to the gradual infi tration of oil into the area of low density formed by the origin extraction of much sand, and the same circumstance, togeth with the presence of old feeders, rendered its removal easy. I the case of a new well in such an exhausted and low-producin district there would not have been sufficient gas left to expel th oil from the sands, and the exudation from compact undisturbe sands would have been very slow indeed without the aid of gas.

Reference is made to this known feature by Huntley,[1] wh refers to wells in the Caddo field of Louisiana and the Glenn po of Oklahoma, that draw their oil from unconsolidated sand, bein pumped incessantly twenty-four hours daily and 365 days yearl to prevent neighbouring wells from breaking down an establishe

[1] Technical Paper 51, Petroleum Technology, Bureau of Mines, Washington

Such a well gives from 10,000 to 14,000 tons of oil, and often from 10,000 to 20,000 tons of sand daily.

The side structure to the derrick is for the erection of a fountain shield to push over the mouth of the well.

FIG. 13. GREAT GUSHER IN THE BAKU OIL-FIELDS OF RUSSIA.

drainage system that ensures a high rate of yield on initial wells. Mention is made of a paper by Hager,[1] containing a diagram showing hypothetical drainage lines that deviate from the well in all directions and act as feeders. Each well is referred to as setting up its own drainage system—from which wells subsequently drilled rarely divert the oil, if production is energetically prosecuted without cessation.

Violent spouters from loose sands, instead of rapidly exhausting the immediate vicinity, actually produce the opposite effect. A close study of the behaviour of a great gusher is exceedingly instructive, and enables one to picture mentally what is transpiring in the earth a thousand, fifteen hundred, or more feet below.

After an initial expulsion of the column of oil in a practically unbroken body, which falls in graceful cascades on all sides as it steadily rises, a fierce ejection of gas ensues, accompanied by oil spray. Then follows a series of intermittent eruptions of sand, oil, and gas in varying proportions, as the well is alternately obstructed by and cleared of masses of sand that choke the tubing and are expelled, causing columns of oil to be thrown to a height of several hundred feet. These alternate obstructions and relief caused by detached fragments of strata, which momentarily plug the tubing and then become ejected, throw violent and changing pressures on the strata from which the oil is liberated. Such action occasions a vibration that causes the ground to quiver for some distance around, and it occasions a disintegration of strata for a radius far beyond that which would result from a gentle flow.

The action of violent gushers, besides discharging enormous volumes of sand, thus creating favourable conditions for accumulation, causes the formation of channels from long distances, and sometimes brings about connection with other oil sands, the contents of which augment the yield.

Careful drilling will enable a succession of rich oil sands to be penetrated and passed if the wells are not bailed, and no agitation is set up which would induce a flow, and consequently initiate the

[1] "Geological Factors in Oil Productions," *Min. and Sci. Press*, Vol. CIII., December 9, 1911.

action just described. This feature was understood and put into execution by some of the most skilful operators in Baku, who, when developing new rich properties, anticipated very violent eruptions that would in most cases destroy their casing, and probably cause the loss of the well. It was, therefore, a practice to carry a well through several rich sands before testing, with the result that after the flush production of the deepest source had been discharged, and the casing had collapsed as anticipated, the weakened casing broke at the next source, and eventually at the third upper source, as the second in turn lost its great gas pressure after a heavy yield. Some wells treated in this way have given 500,000 tons (3,750,000 barrels) of oil, and other wells sunk later, near by, to the same sands, have given normal yields for many years without the dangers of collapsed casing which the initial ones suffered.

In Russia and Roumania, where the oil sands are loose, engineers are well acquainted with the importance of encouraging the excitement described, and of keeping open channels once formed. Wells may be closed in and controlled by valves, but a neighbouring operator who has a well in the same sand will at once derive benefit, and may induce the main flow of oil to his well. The original well may never be induced to flow again, although it may continue to give a good production by bailing.

Many examples could be quoted of the connection between wells separated sometimes by long distances. The choking by sand or closing artificially of one well may lead to the immediate activity of one near by. An example which has given rise to much reflection occurred in Roumania in 1912-13. A gusher flowing 1,000 tons (7,500 barrels) daily was struck at Moreni, when a neighbouring operator was within a few feet of the same source. The authorities forbade the neighbour from drilling on account of the alleged danger from gas, which saturated the surrounding air. Appeals failed to reverse this decision, and for a year the well flowed, giving in that period over 300,000 tons (2,350,000 barrels) of oil, when, had there been no restrictions, this volume of oil would certainly have been distributed among one other, if not more operators, who would have reached the source

PLATE XV.

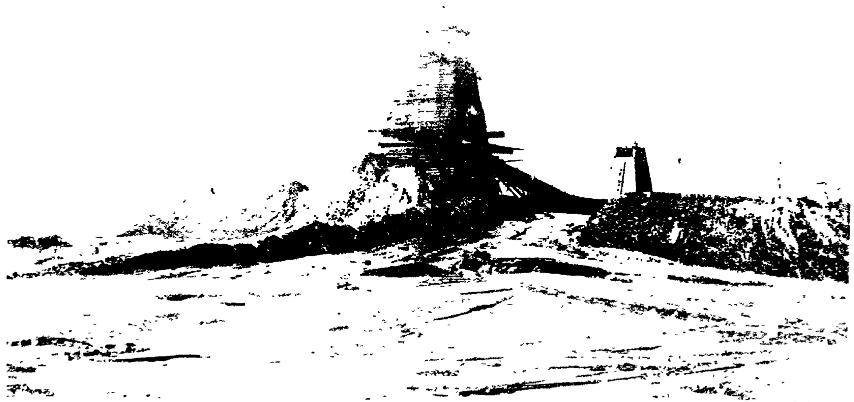

FIG. 14. GREAT FLOWING OIL WELL IN BAKU OIL-FIELDS.
Showing streams of oil and accumulation of discharged sand, almost burying the derrick.

[To face page 138

in time to share in the production, if not to deflect the flow entirely.

The world-famed "Oleum" property (Group XIX.) in Bibi-Eibat, Russia, owes its great productivity to the phenomena under discussion. It was the earliest property developed in the oil-field, and it was here that the greatest and most numerous gushers were brought in. From 27 acres between 8,000,000 and 9,000,000 tons (60,000,000 and 67,500,000 barrels) of oil were extracted in thirty years, and not less than 500,000 tons of sand have been ejected or raised with the oil. The sponge thus formed, aided by disintegrated fault planes, was continually replenished by inflowing oil from all around, as its contents were abstracted by bailing. The property thus acquired and retained a value never approached by any of the surrounding lands which, at a later date, entered development. In this case the water factor, to which reference is made later, largely entered.

The sensitiveness of petroleum wells is not generally appreciated. A sudden diminution or cessation of yield is not natural, and must be due to abnormal causes demanding careful investigation. Oil sands do not suddenly run dry, nor momentarily acquire greater saturation, and great fluctuations of yields are due to subterranean disturbances which should be studied. Influxes of oil are naturally attributable to subterranean land-slides opening up a wider area, as the great inrush of sand which is often contemporaneous with the inrush of oil proves. Sudden diminutions of yield are due to checks and obstructions that in some cases clear themselves in time.

A very little change of conditions often has a remarkable effect upon the subterranean movements of oil, as the following selected examples which have come under the author's personal observation will show. A well which had yielded for years dried up, and was set aside for deepening. When prepared for drilling some months later, so much oil was found standing at a high level in the well that it was decided to bail it out. The level fell very little, and bailing was continued, with the result that the well yielded between 20 and 10 tons

(150-75 barrels) daily for many years. Changed conditions had caused the removal of an obstruction isolating rich oil sands in the vicinity.

Oil from a flowing well in the Bibi-Eibat oil-field of Russia on one occasion found admission to an abandoned oil well near by, down which it flowed in considerable quantities, with the astonishing result that this old well commenced to flow with great vigour, and yielded immense quantities of petroleum. This was evidently due to the subterranean excitement set up by the introduction of great volumes of oil, which either opened up a new source previously excluded, or dispersed an obstruction that had for years effectively excluded oil.

In the year 1910 the author was requested to visit Roumania, where an exceedingly productive well had suddenly ceased to yield, under circumstances that made it certain that the source was not exhausted. After investigation on the ground, water was pumped into the well through a hose for several hours without rising high in the casing, and when bailing was resumed oil was found instead of water, and the well within several hours commenced making periodical flows of oil. At intervals of a few months this conduct and treatment were repeated, and the well in 1914, nearly four years later, was still giving a good production.

The danger of totally checking the flow of a well was well illustrated in the Peruvian oil-fields, when a violently flowing well was closed by a valve. On subsequent opening, when provision for storage had been completed, the well failed to respond, and was found dry. Four wells were drilled in succession in a circle around the first well, and within 50 ft. of it, without obtaining any production. This particular well was located close to a fault of no considerable throw, and doubtless the oil found admission through this channel, which became firmly choked when the high pressure was closed in.

There is no doubt that in many cases the artificial introduction of large bodies of water, or preferably oil, is beneficial in clearing obstructions in wells, but as its indiscriminate application might lead to deplorable and irreparable damage, it is well to

take advice upon such matters, and let each case be judged by circumstances.

Approach to a faulted zone of disturbed ground in some oil-fields is fraught with risk of failure, and sometimes absolute danger, but in other regions it is along the fault planes that the greatest producers are struck. The employment of high-power explosives in hard oil sandstones or dolomites to induce fractures is, in some fields, a recognised procedure, owing its origin to an appreciation of the benefits of fissured strata. Several leading operators in the Baku oil-fields, as far back as 1900, observed the influence exercised by faults of sufficient throw to locate their position, and measure their displacement and hade at the surface. A series of exceptionally large gushers were found to be so located that inclined faults were struck at considerable depth, and this information led to the location of wells to strike known faults at estimated depths.

Mrazec has long called attention to the importance of the junction planes between the Miocene Saliferous series and other newer strata reclining unconformably against them, and it is near them that great producers have been located in Roumania. This feature is particularly noticeable at Moreni and Baicoi, where extremely prolific gushers have resulted.

Attention should be called to the possible influence of wax in oil-fields yielding paraffin-base oils. That wax is deposited in wells is abundantly proved by large masses cleared or ejected from bore holes at intervals, and by the accumulations on the pump tubing and pump valves. Sir Thomas Holland has called attention to this feature in the Yenangyaung oil-field of Burma, and mentions *inter alia* that two opposing factors are at work. Temperature due to depth tends to keep liquid the wax, whilst loss of dissolved gases and lighter products with diminishing pressure reduces both the solvent properties and temperature of the oil, and favours the deposition of wax. Producers in the Boryslav-Tustanowice oil-field of Galicia have long appreciated the sealing effect of precipitated wax around the base of bore holes, and have evolved a process of swabbing (see p. 482) which draws in the accumulating wax, and assists

in keeping the rock pores open. Notwithstanding this, the influence of wax separation is likely to effectually obstruct free movements of oil from a distance, and the radius from which a well would draw its supply of oil would be less than in asphaltic oil-fields. Possibly the distance would diminish with the age of the field.

The maximum yield of such a field might only be obtained by a far more congested distribution of wells than caution and economy dictated in normal circumstances. Wells twenty years old were, in 1914, being regenerated with great success by an electrical process in the Oil City district of Pennsylvania, the inventor of the process contentedly accepting his payment out of increased productions following the melting of wax which had previously checked the inflow of oil.

Water often exercises as powerful an influence upon the movements of oil during the development of an oil-field as it did in its original formation. Many of the greatest producing wells of the world have become subsequently flooded by water, suggesting some connection between the water and oil. Old Baku drillers positively affirmed that where there was no water there was no oil, their meaning being relative only, and referring to "flowing" oil. Deprived of gas from hundreds of vents, oil sands do not readily deliver up their contents, and in the case of viscous oils of heavy density, where friction is great, a point is soon reached where the rate of percolation into the wells is too slow to allow of remunerative extraction.

A limited contamination with water is probably always an advantage, and is the salvation of some fields where absence of gas, density of beds, or viscosity of oil reduces movements to nearly zero, when the initial gas pressure has diminished. Mingling with water that was originally present or subsequently entered the sands, oil is rendered more fluid, and the mixture more readily flows to points of abstraction. The following pertinent paragraph appears in the 1904 Report on the West Virginian Geological Survey, and shows that the phenomenon was observed in that part of the world :—

"When salt water is found in connection with the oil as in the 'Hundred Foot' district of Butler County, Pa., or the Sistersville field of West Virginia

and Ohio, most operators consider that a much greater proportion of the oil can be secured than where the salt water is absent, since the water acts as a rinsing fluid to flush the petroleum out of the sand, and bring it freely into the well. It is also claimed by the practical oil producers that the tendency of the rock to become clogged up with paraffin is much less when the petroleum is accompanied with salt water than when it is absent, so that for both of these reasons it is most probably true that the sand will yield up a greater portion of its oil when the latter is accompanied by salt water."

Malcolm Munn also refers to the contemporaneous exhaustion of water and oil in the Sewickley quadrangle of Pennsylvania in the same "hundred foot" sand, and the universal association of the two fluids in operated pools.

Some oil-fields in the final stages of exhaustion, like that of Petrolea, Ontario, Canada, owe their very existence to the presence of water which percolates into the nearly exhausted porous dolomites, rinsing out their remaining contents, which are pumped from numerous wells towards which the mixture flows. Advantage is taken of spring rains or a large freshet at Oil Springs, Lambton Co., Ontario, to pump oil washed from the Corniferous limestone, and raised to certain points on the anticline. Certain wells were pumped in progressive rotation as the water advanced or receded, carrying with it extracted oil.[1]

The present yield of the great Baku oil-field is mainly due to the prevalence of water, which, gaining admission to the exhausting oil sands, rinses them and carries their contained oil to hundreds of points of extraction. Many very payable wells give five volumes of water to one of oil, and a proportion of two of water to one of oil is exceedingly common. Few oil-fields, indeed, are entirely free from water, and in many the quantity of water diminishes as the field develops. Saturated water sands, at first demanding expensive methods for the exclusion of their contents, discharge slowly into the oil sands beneath as the latter become exhausted, each faulty or damaged well providing a passage for its descent, and each disturbed fault plane a possible channel for its wider distribution.

Descriptions of several interesting wells given below will illustrate the influence of the features just described. The pioneer

[1] Technical Paper 51, Petroleum Technology 11, L. G. Huntley, Bureau of Mines, Washington.

well in the Mamakai district of Grosny, Russia, flowed with such violence that all endeavours to effect its control were fruitless. The oil and gas opened up passages in the earth around the well until the site more closely resembled a mud volcano than an oil well, and for years its output was allowed to flow to waste.

A well sunk to a depth of 2,860 ft., by the Union Oil Company in Santa Barbara Co., California, in 1904, began to flow at a rate of 1,300 tons daily, ejecting at the same time much loose sand, but attempts to cap the well met with no success, as the oil commenced flowing from numerous cracks which opened in the ground for a radius of 50 ft. around the well.[1]

In 1908 a deep well near San Geronimo, south of Tampico, Mexico, flowed with such prodigious force that fissures were opened up in the earth for a radius of 250 ft., from which were expelled oil and gas, producing in a short time a crater with an area of 25 acres. This area was ultimately transformed into a lake of oil in which the derrick and machinery were engulfed. Most of the oil was consumed in a fire which broke out and burnt for forty-eight days, during which time some 2,000,000 tons of solid matter was ejected with the liquid. The oil was eventually followed by warm water, which flowed in sufficient quantity to form a river.

The Lake View No. 2 well of the Midway field of California gave an estimated initial yield at the rate of 40,000 barrels daily, and a total of about 3,000,000 barrels (say 425,000 tons) in a little over five months. Water gradually increased until, towards the end of the flow, there was 60 per cent. present. The violent eruptions caused the earth to cave in, forming a crater 75 ft. in diameter, in which pool the escaping oil and gas caused violent ebullition.

In 1914 a violent gas well, 8 miles north of Corpus Christi, Texas, resulted in the earth opening up, and eventually swallowing derrick and machinery, a cavity 100 ft. × 60 ft., from which gas escaped in great volumes, marking the site. So great was the disturbance created that gas issued from oil wells 1,000 ft. distant through fissures in the earth.[2]

[1] "The Production of Petroleum in 1904," United States Geological Survey.
[2] *Oil and Gas Journal*, 14th December 1914.

Such violent eruptions as those described could not fail to induce a movement of oil unattainable under quiet conditions.

It appears certain that isolated volumes of water trap and retain bodies of oil under pressure under certain conditions, and that the expulsion of the oil when relief is afforded by drilling is followed by an invasion of the water which caused its isolation and accumulation.

That the development of an oil-field might cause a certain redistribution of oil is an obvious deduction. Baku producers assert that such occurred in parts of the Russian oil-fields, areas originally unproductive yielding oil at a later period. The same is reported from the Appalachian oil-fields where the relief of gas under great pressure has been followed by admission of oil.

The beneficial influence of admitted water to oil strata in areas approaching exhaustion is discussed at some length by Huntley,[1] in a publication of the Bureau of Mines. Attempts to flood oil-bearing strata, with a view to concentrating oil, have met with indifferent success in Pennsylvania, mainly on account of insufficient data being available bearing on underground conditions, thereby rendering predictions uncertain. On monoclinal dips, water admitted at strategic points will travel down the dip and carry oil in its path to pumping wells, but in regions of low dips, variations of porosity and partial vacuum applied to wells may cause fluids to travel laterally or up the dip. It is agreed that admitted water could isolate and concentrate bodies of oil under some conditions, causing certain groups of wells in the affected area to give high yields for a time.

Conflicting interests with divergent opinions have proved an obstacle to the testing of large areas in this way under scientific direction. That the subject warrants investigation is obvious, and good results can be confidently predicted in certain areas where comparative regularity of sands in thickness, texture, and dip minimises uncertainties to a negligible quantity.

Exhaustion of oil can be traced and followed in certain unfaulted monoclines, where sand lenticles display fair regularity,

[1] "Decline of Oil Wells," L. G. Huntley, Bureau of Mines, Washington, 1913.

and there is little water. Gravity alone is the determining factor when once the gas pressure has been exhausted, and the levels of oil in wells high up on the dip diminish, till at length the sands are dry, and those lower on the dip continue to yield good productions. The progress of exhaustion down the dip could be well traced in the main sand of the Maikop oil-field, the richest eruptive area becoming quite barren within two years, following active development.

The important part played by water in oil-field development cannot be over-estimated, and the high water contamination in so many of the greatest flowing wells is more than a mere coincidence. The quantity of water usually appears in increasing quantities, and it may play to some extent the part that gas played in the earlier period of the eruption. In Russia, California, Galicia, Roumania, Texas, Oklahoma, and Egypt, large flowing wells have exhibited this feature of increasing water contents.

A phenomenon known to drillers is that of a well "drilling itself in." The casing of a well, if left unsupported at the surface, and lodged on soft strata, sometimes sinks deeper into the sands or strata, as the base is eroded by inrushing oil and gas beneath the shoe. A lower stratum of the oil bed or a deeper unsuspected source has sometimes been tapped in this way, considerably augmenting the yield. One well of exceptional productivity, under the author's direction in the Baku oil-fields, was found to owe its value to the casing slipping to a deeper oil sand, the fact only becoming known when the well was eventually taken in hand for repairs.

Area Influenced by Producing Wells and their Spacing.—The most economical development of oil-fields is ensured by such a spacing of the wells, that, whilst no two wells affect each other, the intervening area is commercially exhausted of its contents within a reasonable period, without leaving undrained patches. This ideal can never be achieved in practice, but it is the object of scientific operators to ascertain by trial and application of divulged data the most economical distribution of wells over an area. Obviously, calculations of this nature are much simpler where single or several well-defined strata of

persistence cover considerable areas with slight variations of level and little faulting. In the sharp flexured, crushed, and faulted strata of Tertiary oil-fields such calculations often have little or no value, as keen competition for holdings in rich fields of strictly restricted lateral width has led to so much subdivision into small areas, that competition, and competition alone, dictates the policy of producers.

Before discussing the problem, it would be well to make a few hypothetical calculations to form an idea of the rock volume involved in the yield of oil to wells of various capacities. Consider first the great flowing wells which have yielded, say, 500,000 tons of oil. At 42 cub. ft. to the ton this volume of oil is equal to 21,000,000 cub. ft., and if we assume a pore capacity of 20 per cent. by volume of the sand, this is equal to the exhaustion of 105,000,000 cub. ft. of sand, equal to $\frac{105,000,000}{43,560} = 2,400$ ft.-acres. If to the oil sand is assigned an average thickness of 100 ft., this is equivalent to the exhaustion of $\frac{2400}{100} = 24$ acres of horizontally disposed strata. The extent of lateral influence naturally varies with the dip of the strata, although it would be perhaps presumptuous to consider this as a geometrical function of the angle of dip. The main point, however, at issue is the immense volume of sand that must come under the influence of a great gusher, unless the oil is contained in strata of much greater porosity than is usually supposed, or lies secreted in unfilled fault planes.

In the above calculations no allowance has been made for the gas, which practically always accompanies the oil. If the moderate volume of 500 cub. ft. of uncondensable gas per ton (66.6 cub. ft. per barrel) of oil is allowed,[1] and the depth of the well is assumed to be 1,500 ft., and earth temperature as 27° F. higher than atmospheric temperature, an additional volume must be added per ton of oil ejected, which, taking a gas pressure

[1] This volume is based on a large number of direct measurements of gas from average wells, and would probably be a fair approximation for many fields with a settled production.

at 645 lbs. per square inch as the hydrostatic head for the depths named, would amount to approximately 12 cub. ft.

In the early stages of development the above figures would be far exceeded, and sometimes the volume of permanent gas, or gas dissolved in the oil, would far exceed the volume of oil flow.

It will thus be seen that approximately 12 cub. ft. per ton of oil may be added for volume of gas, or say for convenience 25 per cent. of the volume of oil under the conditions specified.

In this connection it is interesting to note that a 40,000,000 cub. ft. gas well, such as those struck in parts of the Texan, Louisiana, and Oklahoma oil-fields, if taken at a pressure of fifty atmospheres (735 lbs. per square inch), is equivalent in volume to a daily yield of about 17,000 tons of oil if allowance is made for proportion of liquefiable products.

Applying these hypothetical deductions to a typical well of 5,000 tons ultimate capacity in the nearly horizontal, little flexured fields of, say, Oklahoma or Kansas, where the average thickness of productive sand is 20 ft., the depth 1,500 ft., and the proportion of extractable oil is 10 per cent., the following is arrived at. The above output has a volume of about 210,000 cub. ft., equal to the contents of 2,210,000 cub. ft., or say 48 ft.-acres, and consequently equal to the drainage of $\frac{48}{20} = 2.4$ acres. Add to this above 25 per cent. for contained gas, and the area becomes 3 acres.

Examine for a moment the output of one or two selected properties. Plot XIX., Bibi-Eibat, Russia, with an area of 27 acres, has furnished about 9,000,000 tons of oil, equal to a volume of 378,000,000 cub. ft., or 14,000,000 cub. ft. per acre. This represents, with the addition of 10 per cent. for uncondensable gas and no allowance for losses, a volume of oil that would cover the property to a depth of 402 ft., and if a 20 per cent. capacity is assigned to the oil sands a thickness of 2,010 ft. is reached, obviously absurd where the main horizons are confined to a vertical thickness of some 2,000 ft. Oil is evidently drawn from a large radius, and the example is instructive in illustrating the extent to which well-located and

energetically developed properties can attract oil from surrounding territory.

Grosny affords an example of excessive enrichment in a less rich oil-field. The Akhverdoff property, still one of the best producers in the field, has yielded 42,000 tons of oil per acre, equal to a 40.5 ft.-acre volume. Assuming in this field an average 10 per cent. recoverable saturation, this would correspond to the contents with gas of about 500 ft. of strata; a very excessive figure for the field, and clear proof of lateral travel.

In some of the richest districts of the Baku oil-fields as much as 20,000 tons of sand per acre have been ejected with the oil from wells.

The above calculations serve to prove how illusory prophecies of prospective yields may prove in the Tertiary flexured type of oil-field, also the fair approximation possible in certain less disturbed areas. The area influenced by a productive well is often considerable. One well may flow unaided so long as another does not, but on the second developing a natural flow the first ceases. An influx of water in one well will often be transmitted within twenty-four hours to a whole series of wells. Cessation of pumping in one well leads to improved yield of another, and at times certain wells may be pumped for water alone, suspension of such pumping leading to the flooding or reduction of yield of other wells in the vicinity. Cement fluid used for excluding water has been traced far away in wells bailing from depths near that horizon. Occasionally in rich ground the activity of one well will excite others near by, causing them to flow also. Almost every oil-field attendant can recall numerous cases proving the sympathy of wells.

Where individual plots are of limited extent and surrounded or bounded by active competing neighbours, it is usual to drill hastily a large number of wells along the boundaries without any regard to economy. Custom and mutual goodwill, in some fields of medium richness, have reduced the evils of such competition, but generally in the rich fields the greatest efforts are made by conflicting interests to drill along boundaries, the earlier

wells securing more than their due share if oil is distributed fairly equally in a radius round the well.

Spirited rivalry between neighbouring producers always conduces to wasteful development, and in such fields as Spindle Top, Texas, Bushtenari and Moreni in Roumania, Boryslav in Galicia, Yenangyaung in Burma, and the Baku oil-fields of Russia, where the land has been divided into small blocks, hundreds of thousands of pounds have been deliberately wasted in sinking dozens of wells in close proximity to each other, where the same quantity of oil could have been extracted from perhaps one-tenth of their number. The following pertinent paragraph refers to the operations of Spindle Top:—[1]

"The conditions should have suggested to those concerned in the development that a few wells properly distributed would have drained the pool as effectively as the large number which have been drilled."

In oil-fields where areas are generally developed in blocks of hundreds of acres or square miles, there is no fear of the attacks of neighbours, and wells are usually spaced so as to give each well an area of from 1-10 acres. A spacing of 4-5 acres per well is a very common practice in oil-fields where the dip of the beds is small. Gas wells are much more widely spaced, as the natural pressure is often required to expel the gas to points of consumption. One well per 640 acres is a reasonable distribution in a country of flat-lying strata. Five wells per acre are not uncommon in the Baku and Roumanian oil-fields, but there is some justification for close spacing in the very rich fields, and especially in the sharp-flexured fields where excessive concentration has occurred along a narrow strip, and a whole succession of oil sands or faulted zones provide storage for accumulation.

The direct volumetric equivalent of spacing on horizontal or slightly inclined strata could be obtained by horizontal projection of inclined beds; but such would bear no comparable relationship, as highly inclined beds would greatly facilitate upward movements of gas and oil. There might also be areas on a portion of any

[1] "Oil-Fields of the Texas-Louisiana Gulf Coastal Plain," by C. M. Hayes and W. Kennedy. United States Geological Survey, Bulletin 213, 1903.

circumscribed circle requiring to be eliminated through extending beyond the area of enrichment.

The most effective distribution of wells to ensure equal drainage, so far as that is possible under oil-field conditions, is to locate the wells equidistant, *i.e.*, in equilateral triangles. Circles drawn round the three apices then give a minimum of overlap, or alternatively leave the minimum of area outside a radius equal to half the length of one of the sides of the triangle. Locations on steeply inclined flanks of anticlines or monoclines are sometimes spaced so that those down the dip are nearer than those along the strike, but in all cases wells on a second line along the strike are spaced to be between those on the first line.

Offsetting has become a recognised practice in American oil-fields where acquired customs often supplant law. Notwithstanding the absence of obligation to drill and even the provision for payments as compensation for delay in drilling, there is an implied covenant to drill offset wells if a productive well is drilled near the boundary on a neighbouring plot. It is claimed that failure to drill within a reasonable time seriously impoverishes the undeveloped land, and the owner is therefore entitled to relief.

Mutual goodwill and sound common sense have gradually established a custom in America of not drilling nearer than a fixed distance, often between 150 ft. and 300 ft. from the boundary of the property; consequently, a minimum of 300-600 ft. between wells is obtained, and this serves to avoid the wasteful competitive drilling that so often characterises the development of European oil-fields. As each well is drilled along the boundary of one property an offset is demanded and drilled in on the adjoining property to maintain a balance. The author has himself initiated and put into practice elsewhere this reciprocal arrangement without any recourse to law; and the custom is well worth cultivating in many fields where competitive drilling is now in vogue.

Yield and Life of Oil Wells.—Life and production of oil wells only occasionally bear a direct relationship to each other, and to the degree of exhaustion of the beds to which the wells are

sunk. Damage sustained by the casing lining the well, infiltration of imperfectly excluded water, accumulation of impervious sediment, or precipitation of wax may partially or entirely exclude the admission of oil from beds very far from exhaustion. The majority of wells in most oil-fields are abandoned through defects such as those enumerated, and not in consequence of exhaustion. There is furthermore the commercial aspect, an increase or diminution of the price of oil assigning to a certain production a remunerative or unremunerative value. Groups of abandoned wells often acquire considerable value, and become the centre of renewed activity with a rise of prices.

In all oil-fields there are certain fortunate wells that have escaped or resisted all the troubles suffered by most oil wells at some period of their life, and they continue to yield for twenty or more years, though on a diminishing scale. Two wells of West Virginia were recorded in 1904[1] as having been pumped for forty-three years, and were still giving one to two barrels daily; and others in the Appalachian fields have been pumped without interruption for over thirty years. The Gantz well of Washington Co., Pa., was finally abandoned in 1911, after yielding since 1885, declining gradually in production from 55 barrels to one-fourth of a barrel daily; and at the same date the Triangle well of Allegany Co., New York, completed in 1879, was still yielding at the rate of one-eighth of a barrel daily, pumped twice weekly.[2]

Appalachian wells in 1907 were officially assigned an average life of seven years, Texan wells four years, and those of California six years.[3]

Many wells in the Russian oil-fields of Baku have given remunerative yields for from ten to twenty years. Certain wells in Peru have been pumped uninterruptedly for fifteen years, and Roumania and Galicia afford numerous similar examples of prolonged life of isolated wells amidst others less fortunate.

There is in almost every oil-field sufficient uncertainty in the

[1] "West Virginia Geological Memoirs, 1904."
[2] "Oil Resources of U.S.A., 1911."
[3] "Petroleum Resources of U.S.A.," 1909.

results of drilling to inspire a speculative interest surpassed by few industries, not excluding metal mining. Amidst what might be called bread-and-butter wells there are always surprises which represent a fortune of no mean magnitude to the fortunate proprietor. The reasons for these are discussed elsewhere, but it is inadvisable to rely upon such exceptional events in practice, and all calculations should be based on average yields of normal wells. Still, the incentive is not without its reward, as it has been the cause of persistent and eventually successful efforts to extend areas and search for unknown deep sources that would otherwise have remained undisclosed.

One single gusher will often recoup many times over losses occasioned by years of fruitless or profitless drilling. Although a welcome advent, it is bad policy to work only for gushers, and in search of them to neglect the prolific sources which are the mainstay of all successful oil enterprises.

Carefully compiled statistics of the yield of oil-fields at successive intervals during their development afford a mass of instructive information that will reward study. The steady diminution in proportion of flowing oil to that artificially abstracted, and the interesting and varying curves of average production per well obtained by plotting, indicate the extent and speed of exhaustion, and enable cautious operators to long foresee events that those less observant have missed.

Fig. 15 shows diagrammatically the monthly yields of a group of wells in the Saboontchy oil-field of Baku, Russia.

Selected wells in many fields have given prodigious quantities of oil both as initial yield and in the aggregate. Quite a number in the Saboontchy-Romany and Bibi-Eibat oil-fields of Russia have given consistent daily yields of 10,000-16,000 tons (75,000-120,000 barrels) for days and weeks, and totals of from 200,000-1,000,000 tons (1,500,000-7,500,000 barrels) within a year or two. Equally prolific wells have been struck in the Mexican oil-fields; one well at Dos Bocas, south of Tampico, was estimated to have given 840,000 tons (over 5,000,000 barrels) within two months. Wells that have yielded 3,000,000 tons (21,000,000 barrels) have been reported from Mexico.

One classical well in Bibi-Eibat (Plot XIX.) gave nearly 500,000 tons (3,750,000 barrels) in thirty days by an uninterrupted flow, and in 1912-13 a well at Moreni gave 400,000 tons (3,000,000 barrels) in seventeen months. At Jennings Pool, Louisiana,[1] in 1904 a well, which was described as the largest producer ever struck in America, gave 170,000 tons (1,275,000 barrels) of oil in four months, an average of nearly 1,500 tons daily. Wells in Texas, California, and Roumania have given initial daily yields of 8,000-10,000 tons (60,000-75,000 barrels) of oil. A well in the Campina oil-field of Roumania[2] ejected 14,000 tons (105,000 barrels) of oil and 150,000 tons of sand within thirty hours, and in both Roumania and Galicia there are many wells that have standing to their credit productions of 50,000-100,000 tons (375,000-750,000 barrels). The original well in Maikop, South Russia, flowed uncontrolled 50,000 tons (375,000 barrels), and this yield was exceeded by another well in 1915. Reference is made on p. 26 to a 3,000,000-barrel well in Roumania.

Isolated wells described above bear, however, no relationship to the average production of wells in the fields in which they appear. They are due to the occasional coincidence of a number of strictly local conditions, lithological and structural, that are rarely repeated, and they usually deplete the immediate vicinity sufficiently of gas to prevent their duplication.

The average total production of oil wells during their lifetime varies greatly in different oil-fields and at different periods of development of the oil-field. About the year 1892 when there were 448 productive wells in the Baku oil-fields, the average ultimate production per well in the best parts of the fields was not less than 90,000 tons (675,000 barrels), but in 1912 this had fallen to about one-third, and the average still decreases. In 1895 the average annual yield of all wells in the Baku oil-fields exceeded 10,000 tons (75,000 barrels), but in 1909 the average had fallen to 4,000 tons (30,000 barrels), although the wells in the latter year averaged 60 per cent. deeper than the former year.

[1] See "Petroleum Resources, U.S.A., 1904."
[2] Well No. 65, Steaua Romana Company.

results of drilling to inspire a speculative interest surpassed by few industries, not excluding metal mining. Amidst what might be called bread-and-butter wells there are always surprises which represent a fortune of no mean magnitude to the fortunate proprietor. The reasons for these are discussed elsewhere, but it is inadvisable to rely upon such exceptional events in practice, and all calculations should be based on average yields of normal wells. Still, the incentive is not without its reward, as it has been the cause of persistent and eventually successful efforts to extend areas and search for unknown deep sources that would otherwise have remained undisclosed.

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At the most prolific period of the career of the Boryslav-ustanowice oil-field of Galicia, the average lifetime production of ells in the best part of the field was estimated at 37,000 tons :77,000 barrels), the period of natural flow being often quite ɪng. Normal Tertiary oil-fields with loose sands usually yield om 5,000-10,000 tons (37,500-75,000 barrels) per well, ut in some of the more compact sands in less flexured regions ıe yield per well may be as low as 1,000-2,000 tons ,500-15,000 barrels). In parts of the Appalachian and)klahoma oil-fields, where the redeeming feature lies in easy and heap drilling, ultimate productions of 500-1,000 tons (3,750-,500 barrels) per well are usual. Spindle Top wells, during he four best years of their progress, gave an average of 3,800 ɔns (about 24,000 barrels[1]). During the development of the est horizons of the Yenangyaung oil-fields of Burma average ltimate yields of from 12,000-15,000 tons (91,000-112,000 ıarrels) were obtained.

Under certain favourable circumstances, both as regards uality of oil and facilities of marketing, it is surprising what small ields of oil permit of profits, and even encourage development. Vells in Ohio, Indiana, Pennsylvania, and West Virginia do ıot yield more than from 2-6 tons (15-45 barrels) monthly ıfter a brief higher initial yield, and there are extensive groups of wells averaging 3,000 ft. in depth, that give only half ı barrel ($\frac{1}{15}$ ton) daily. The persistence of oil wells is well llustrated in New York State, where in 1911 there were groups of twenty wells pumping less than .025 barrel per well per diem without loss, if unattended by gain.[2]

Wells yielding only 3 tons (22.5 barrels) monthly are being regularly pumped in the Ontario oil-field of Canada. Even in California there are certain oil-fields where the low grade asphaltic oils are remuneratively extracted when the production per well has fallen as low as 1-3 tons (7-21 barrels) daily.

[1] In the conversion of tons to barrels or vice versa, for convenience, ordinary light oils have been assumed as equal to 7.5 barrels per ton, heavy oils as 7 barrels per ton.

[2] "Petroleum Resources, U.S.A., 1911."

Oil wells usually give a flush production in their very early life, often not less than 50 per cent. of their ultimate yields spread over many years. The production curves on the various charts in Chapter XIII. illustrate this feature clearly; the relative areas enclosed by the curve and the base line indicating comparative yields. Production curves gradually flatten with age until they assume nearly straight lines, but in the initial period they show prominent peaks if oil is derived from loose sands like Russia, Roumania, and California, or from porous dolomites. As an oil-field develops the curves flatten more quickly, until the initial peaks quite disappear. Ratio of flush to settled production depends upon the nature and porosity of the sands, the extent of development of the field, viscosity of oil, and quantity of gas, and since these are variables the ratio consequently varies with the age of the field. Until gas pressures diminish, at least 50 per cent. of the ultimate production is obtained within the first year of exploitation, and where oil is only obtained by firing heavy charges, the first month's production may represent a considerable proportion of the ultimate. Californian records collected by the Bureau of Mines indicate a very little fall after the early flush yields. Midway wells, in 1913, had indicated a daily fall in average yield of 1 barrel, and Sunset 1.7 barrels. Between 1903 and 1906 the average daily output of Kern River wells, computed from the yearly yield, fell 12 barrels, and between 1907 and 1913 the daily average fell another 3.8 barrels. Coalinga wells had, in 1914, been estimated to show an average decline of .52 barrel a month, or 6.0 barrels a year.[1] Such rates, although a diminishing factor, soon reduce the wells to unprofitable units unless there is a compensating rise in the price of oil, or cheaper means of extraction are practised.

The advisers of the United States Geological Survey computed the average daily productions of American wells in 1907 to be approximately as follows:—[2]

[1] "The Petroleum Industry of California," Bulletin 69, California State Mining Bureau.

[2] "Petroleum Resources of United States, 1909," by Dr D. Day.

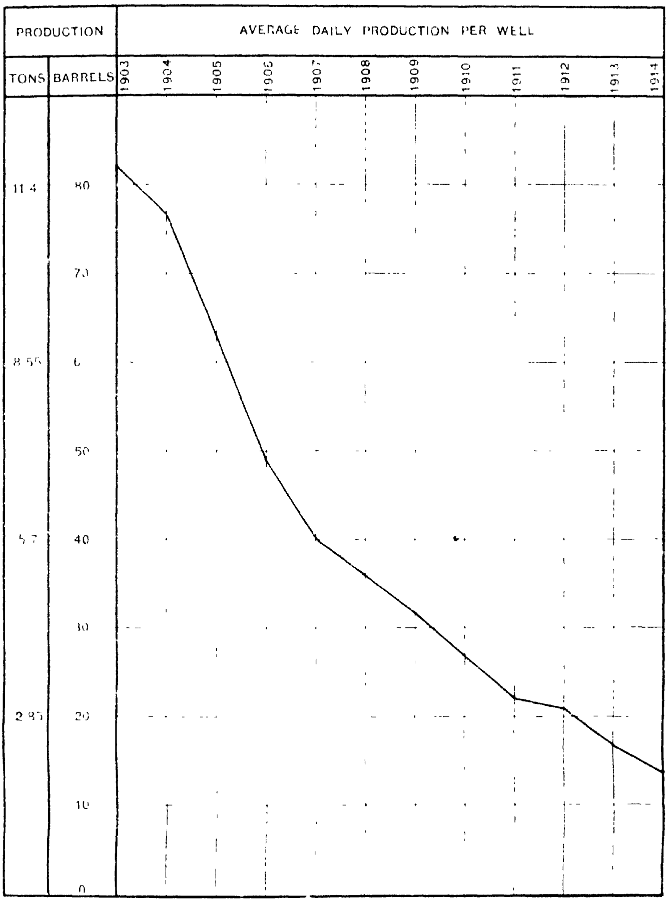


FIG. 16.—CHART SHOWING THE AVERAGE DAILY PRODUCTION OF WELLS IN THE KERN RIVER OIL FIELD OF CALIFORNIA BETWEEN 1903 AND 1914.

[To face page 150

Field.	Yield per Diem.	Approximate Conversion to Tons.
	Barrels.	
Appalachian oil-fields	1.73	.23
California	42.56	6.08
Lima-Indiana	2.74	.39
Colorado-Wyoming	8.35	1.11
Mid-Continent	8.81	1.20
Gulf	19.35	2.76
Illinois	8.37	1.14

Mechanical improvements in the methods of drilling oil wells and extracting petroleum are yearly enabling lower and lower grade properties to be profitably operated. So pronounced is this progress, that lands of little value a few years ago are acquiring considerable importance and realising high prices.

Production and Life of Oil-Fields.—Exhaustion, in oil-field phraseology, is a relative term only, and implies that the oil beds have been so far depleted that petroleum can no longer be extracted at a profit at the moment. An increased market value, a new invention, an improved system of drilling or extraction often invites renewed activity to abandoned areas, and leads to the recovery of thousands of tons of oil from so-called exhausted areas, much in the same way as modern mechanical or chemical methods enable abandoned mines to be reopened, or rejected "dumps" to be re-treated at a profit.

Supplies of petroleum in most oil-fields are derived from a succession of sands separated by unproductive strata, and in some cases the lower productive seams cannot be reached, except perhaps over a limited area, with the appliances in use, or at a cost that renders operations profitable.

Had the price of oil in Russia remained at the figure of 7s. 6d. per ton (24 cents per barrel), that it was in 1901-3 the great Baku oil-fields would long ago have been abandoned and the deep sources left untouched. The old Appalachian oil-fields which have so long remained nearly derelict were in 1913-14 the centres of considerable activity, owing to the price of Pennsylvanian grade oil rising in value from 30s. to 75s per ton ($1 to $2½ per barrel).

Many promising oil-fields have been rendered valueless by water, either admitted to the oil-bearing strata by injudicious drilling, by land disturbances following the extraction of large volumes of petroleum, or its occurrence amidst oil beds. Such eventualities cannot be foreseen, and bring to a sudden and inglorious end the hopes and ambitions, and perhaps careers, of many enterprising operators worthy of better fortune.

Production and life of oil-fields bear only a remote relationship to one another. The two act in inverse or contrary directions, for operators seek to obtain the maximum production of oil, whilst at the same time securing as much reserve territory as possible to extend the life of operations. Individual holdings of large areas promote economical development and long life. Small ownership leads to wasteful development and short life. Cheap drilling inspires a degree of activity that funds never admit of in expensive drilling territory. The latter prolongs the life of an oil-field, but reduces the rate of production; the former has the opposite effect of diminishing the life of the field and increasing the rate of output.

If unmercenary motives actuated operators, and they were uninfluenced by prices of oil, or were in possession of sufficiently large areas to disregard the operations of neighbours on their boundaries, endeavours would be made to locate wells so that the whole underlying oil strata would be commercially exhausted with the minimum number of wells, and consequently the least capital outlay.

The proper measure of the productive capacity of oil-fields is the total volume per unit of area the beds are capable of yielding. The difficulty of estimating this will be appreciated after reading the preceding pages, where the various factors influencing the rate of production are described.

There is, on the part of some geologists, a disposition to estimate the oil contents of sands in much the same way as coal seams or ore bodies, but all such calculations must be accepted with reserve. In new fields only imperfect information is available upon which to base conclusions, and in all circumstances a degree of saturation must be assumed from limited particles of material raised from the wells, and a nominal

volume must be allowed for unextractable oil. Lenticularity of oil sands is a feature itself often imposing strict limitations to volumetric calculations, but irregular impregnation due to variable grades of sand, and partial or entire cementation of portions by carbonate of lime, silica, or other material, introduces uncertainties in most fields, nullifying the value of such estimations.

Other causes which modify estimations of oil contents are found in the location of the area with regard to degree of declivity and direction of dip. Initial wells near the crest of an anticline, where there has been concentration either of gas or oil, yield results that make all calculations appear absurd. Some such localities give only gas, others astounding quantities of oil. In many cases active development at low points on the dip of inclined strata causes so complete exhaustion of the sands at more elevated points that the latter yield merely a small percentage of the oil their position would have entitled them to under other circumstances.

Quite apart from geological features, which detract from the value of such figures, there is the question of the relative development activity on adjoining or surrounding leases. Impecunious, unskilled, or unenterprising leaseholders may have their lands largely drained by rich, skilful, and active neighbours.

Even approximate estimates of the oil contents of well-known oil-fields are difficult to prepare, as few famous fields have been exhausted or abandoned except through some catastrophe. Extensions of existing areas and penetration of deeper sources constantly modify calculations, nevertheless useful figures have been collected which aid one in forming rough approximations of capacity.

Selected parts of Pennsylvania have been estimated by State geologists to yield about 200 tons (1,500 barrels) of oil per acre, and the State geologist of West Virginia considered the oil beds of the State to be capable of giving a maximum of 650 tons (4,900 barrels) per acre.[1] In reviewing the subject in 1909,[2] it was estimated that the average yield on the Pennsylvanian oil-fields would not exceed 100 tons (750 barrels)

[1] "West Virginian Geological Survey," Vol. I., 1904.
[2] "Petroleum Resources of the United States, 1909," by Dr David Day.

per acre, and over the whole Appalachian oil-fields would not exceed 135 tons (1,000 barrels) per acre. In Illinois, where the "pay streaks" average 25 ft. in thickness, the oil-fields are thought to be capable of producing an average of 1,000 tons (7,500 barrels) per acre, 3.8 per cent. by volume.

The Canadian oil-fields have been computed to have yielded about 50 tons (375 barrels) per acre, but the once famous Bushtenari field of Roumania was estimated in 1905 to be capable of yielding 9,000 tons (67,500 barrels) per acre, although the best parts may eventually yield nearly double this quantity.

Spindle Top, the first renowned oil-field of Texas, with a proved area of about 200 acres, gave in four years, from January 1901, 4,650,000 tons of petroleum, or about 23,250 tons (160,000 barrels) per acre, after which it was so far exhausted or flooded that only 95 producing wells remained out of the 1,200 drilled, yielding collectively 800 tons (say 6,000 barrels) a year.[2] Subsequent development in a more cautious manner checked the ebbing output, which in 1907 reached 226,000 tons (1,500,000 barrels).

The Baku oil-fields of Russia supply the most startling figures of capacity. A single plot of 27 acres in Bibi-Eibat (Plot XIX. of The Russian Petroleum Company, Ltd.) has produced in thirty-six years over 8,000,000 tons (60,000,000 barrels) of oil from about sixty wells, or 295,000 tons (2,200,000 barrels) per acre, and in 1914 still yielded 63,000 tons (470,000 barrels). This, of course, is no criterion of the general richness of the field, and only illustrates features explained on pp. 148-49, but it proves the wonderful capacity of oil land under certain circumstances. The oil extracted would fill a reservoir equal in area to that of the property to a depth of 270 ft. The Bibi-Eibat oil-field, with an approximate area of 250 acres, has produced 160,000 tons (1,200,000 barrels) of oil per acre, and in 1914 an output of 1,030,000 tons (7,700,000 barrels) was recorded.

From the Balakhany-Saboontchy-Romany field of Baku with an area of about 2,500 acres, excluding Surakhany, which

[1] "L'Exploitation du Petrole Roumain," I. Tanasescu and V. Tacit.

[2] "Production of Petroleum, 1914," by F. H. Oliphant, United States

extends to the south-east, has been obtained 150,000,000 tons (1,125,000,000 barrels) of oil; in round figures, 60,000 tons (450,000 barrels) per acre. In 1914 this area yielded 3,880,000 tons (29,000,000 barrels) of oil. The oil withdrawn from this rich field would fill a receptacle equal in area to that of the field to a depth of 57 ft.

Roumania furnishes examples of extremely rich oil-fields. An area of about 130 acres at Moreni has in ten years given 4,000,000 tons (30,000,000 barrels) of oil, or 30,000 tons (225,000 barrels) per acre. In 1913 the total output was 981,900 tons (7,350,000 barrels), or 7,000 tons (52,500 barrels) per acre. Galicia supplies one example of fame—the Boryslav-Tustanowice oil-field—where 12,000,000 tons (90,000,000 barrels) of oil have been abstracted from about 1,500 acres, or 8,000 tons (60,000 barrels) per acre. 897,000 tons (6,730,000 barrels) of oil were raised from this field in 1913, indicating its remoteness from exhaustion.

A single sand in the Maikop oil-field of Russia had produced 11,000 tons (82,500 barrels) per acre, about 314 tons (2,355 barrels) per acre-foot, or 30.4 per cent. by volume on the irregular area over which it has been located by drilling, and was in 1913 still producing 80,000 tons (600,000 barrels) per annum. Average Peruvian oil-fields appear to have a capacity of from 1,000-3,000 tons (7,500-23,500 barrels) per acre, but areas of increased enrichment have been struck.

Mr I. Streezhoff in 1910 placed the yield of Grosny (Russia) oil properties at 3,500,000 poods per dessiatine, or 21,000 tons (157,000 barrels) per acre, and stated that from the Akhverdoff property 7,000,000 poods a dessiatine had been extracted, equal to 41,700 tons (310,000 barrels) per acre. The total capacity of 1,600 dessiatines (4,300 acres) at Grosny was estimated at 11,200,000,000 poods (180,000,000 tons = 1,350,000,000 barrels), equal to 40,000 tons (300,000 barrels) per acre.

Oklahoma lands vary greatly in productivity, the yield probably lying between extremes of 200 and 2,000 tons (1,500 and 15,000 barrels) per acre. The yield per acre-foot of oil sand has probably been much greater in the deeper territory than in the shallow belts.

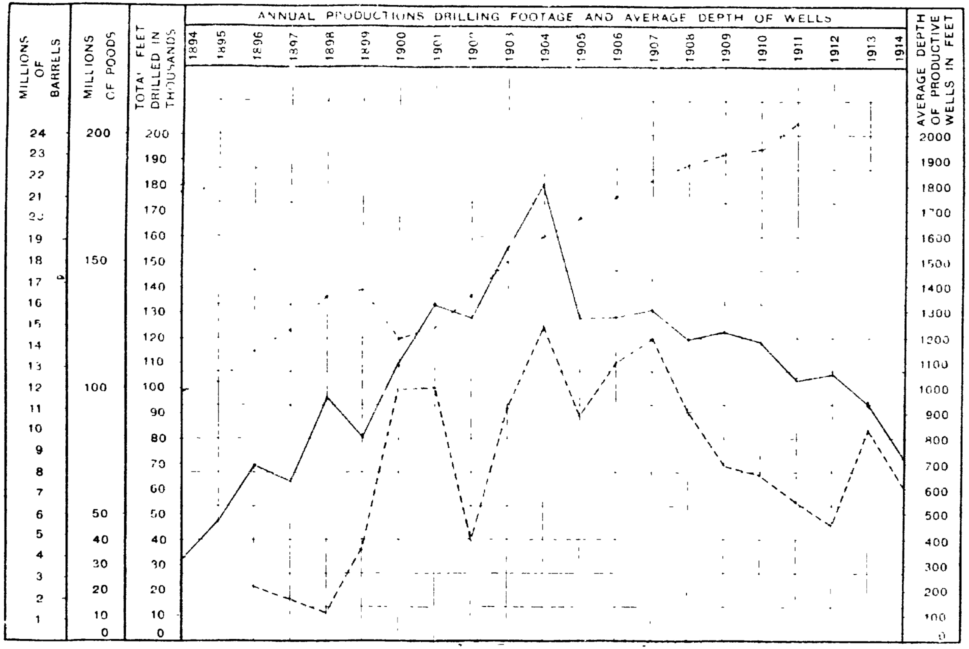
Ten square miles, 6,400 acres, of proved territory in the Kern River oil-field of California have yielded 167,400,000 barrels of oil, that is 26,000 barrels, or 3,714 tons per acre, through the medium of some 1,700 wells. As the oil sands average 325 ft. in thickness, this is equal to 80 barrels (11.4 tons) of oil per acre-foot, or 1 per cent. by volume; the field continues to produce at a rate of 7,500,000 barrels (1,071,000 tons) per annum.

McKittrick, California, provides another example of high enrichment, with a proved and restricted area of 896 acres, that yielded in twelve years 37,103,000 barrels of oil from 270 wells, equal to an output of 41,450 barrels (5,920 tons) per acre. Although drilled up to the extent of one well per 3.3 acres, the production in 1914 was maintained at about 4,000,000 barrels.

The Coalinga oil-field of California, with an area of 22 sq. miles, had in 1913 only been developed to the extent of one well to about 14 acres, and the 1,000 or so wells are often concentrated in certain groups, nevertheless the yield had already reached 138,444,000 barrels, or 9,830 barrels (1,400 tons) per acre. Assuming the average thickness of sand to be 100 ft., this is equal to 98.3 barrels (14.00 tons) per acre-foot, or 1.27 per cent. by volume. This field still produces 16,000,000 barrels (2,280,000 tons) annually.

A common practice of computing recoverable oil contents of sands in California is to allow 10 per cent. of the cubic contents of the sands; this is equal to 780 barrels (say 110 tons) per acre-foot of oil sand.

Careful study of Fig. 17 will afford instruction, as in the curves are revealed all the main features that are reproduced in every oil-field. It represents diagrammatically the development of the Bibi-Eibat oil-field of Russia from its early career to the stage of approaching exhaustion, and shows very clearly the various stages when drilling effort sustained production, and when both deeper drilling and increased number of wells sunk failed to sustain production, and could not arrest the decline. Inconsistencies are introduced by periods of labour troubles and political unrest, and price of oil has been reflected by accelerated or diminished drilling efforts at intervals.



Feet Drilled — Production — Average Depth of Wells

FIG. 17.—CHART SHOWING THE DEVELOPMENT OF THE BIBI-EIBAT OIL FIELD OF RUSSIA FROM ITS EARLY CAREER TO APPROACHING EXHAUSTION.

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Typical Well Logs.—Attached are a few typical well logs from widely separated oil-fields:—

Typical Logs of Wells from Various Oil-Fields.

Well, Neosho County, Kansas, U.S.A.

(Yield, 4 to 5 barrels of oil a day. 5-in. casing to 623 ft.)

	Depth in Feet.
Surface soil	0-20
Brown gravel (fresh water)	20-30
Hard grey limestone	30-56
Sandstone	56-61
Hard grey limestone	61-65
Soft grey shale	65-70
Hard grey limestone	70-75
Soft grey sandstone	75-80
Soft grey limestone	80-115
Soft grey shale (limy)	115-125
Soft grey limestone (water at 128 ft.)	125-130
Hard grey limestone	130-142
Soft grey shale	142-320
Soft light grey limestone	320-335
Soft grey shale	335-370
Grey sandstone (salt water and gas; hole filled up 200 ft.)	370-385
Soft grey shale	385-400
Soft grey limestone	400-420
Shale	420-428
Hard grey limestone	428-458
Soft grey shale (limy)	458-490
Hard grey limestone	490-513
Hard black shale (water, 40 barrels per hour)	513-521
Hard grey limestone	521-528
Soft grey shale (limy)	528-715
Soft grey shale (sandy, top of sand show of oil)	715-720
Soft grey sandstone and shale	720-728
Sandstone (oil sand, 22-ft. pay sand at bottom)	728-752

Well at Humble, Harris County, Texas, U.S.A.

(Gas at 215, 508, 645, 670, and 700 ft. Some oil and much gas between 790 and 950 ft. Pay oil between 951 and 990 ft. Yield, 100 barrels first twenty-four hours. Diameter of well, 11⅝ in. to 310 ft., 6 in. to 950 ft.)

	Depth in Feet.
Soft grey sand	30-40
Hard grey clay	40-60
Hard bluish sand	60-215
Hard grey sand and clay	215-310
Hard blue sand and clay	310-400
Loam grey sand	400-470
Fine grey sand	470-495
Hard blue clay	495-508
Hard blue sand and clay	508-572
Hard blue clay	572-645
Hard blue sand and clay in layers	645-710
Hard blue shale	710-950
Mixed rock and sand (limy)	950-990

Typical Well, Spindle Top, Texas, U.S.A.

(Water flush drill.)

	Thickness in Feet.	Depth in Feet.		Thickness in Feet.	Depth in Feet.
Yellow clay	20	0-20	Blue clay	23	657-680
Quicksand	36	20-56	Shell formation	37	680-717
Blue clay	134	56-190	White limestone	20	717-737
Quicksand	105	190-295	Grey clay	11	737-748
Coarse gravel	20	295-315	White limestone	1	748-749
Blue clay	10	315-325	Grey clay with shells	31	749-780
Hard blue shale	4	325-329	Shells	7	780-787
Blue clay	51	329-380	Blue clay	7	787-794
Coarse gravel	17	380-397	Grey clay	16	794-810
Blue clay	13	397-410	Shells	2	810-812
Coarse gravel	18	410-428	Oil sand	3	812-815
Coarse sand *with gas*	37	428-465	Blue clay	5	815-820
Blue clay	15	465-480	Hard limestone	4	820-824
Blue clay mixed with nodules	15	480-495	Black sand	6	824-830
Quicksand	12	495-507	White limestone	2	830-832
Blue clay	83	507-590	Soft dark shale	13	832-845
White limestone	10	590-600	Soft white limestone	7	845-852
Sulphur and oil sand	2	600-602	Soft dark shale	13	852-865
Blue sandstone	18	602-620	Blue sand rock	5	865-870
Hard white limestone	5	620-625	Quicksand	12	870-882
Blue clay	7	625-632	White limestone	3	882-885
Soft sandstone	11	632-643	Sand *with show of oil*	12	885-897
Hard limestone	1	643-644	Blue clay	10	897-907
Blue clay	8	644-652	Iron pyrites	2	907-909
Soft sandstone	5	652-657	Dark clay	3	909-912
			Oil sand	18	912-930

Well in Salt Lake Oil-Fields, Los Angeles, California, U.S.A.

(Cable tools.)

	Thickness in Feet.	Depth in Feet.		Thickness in Feet.	Depth in Feet.
Clay	36	36	Sandy shale	41	486
Sand and gravel	24	60	Sticky sandy shale	19	505
Heaving sand (first water cased off at 110 ft.)	30	90	Coarse gravel and sandy shale	21	526
Clayey shale	70	160	Sandy shale (4 ft. shell at 632 ft.)	146	672
Sandy shale	90	250	Clayey shale (4 ft. shell at 701 ft.)	29	701
Sandy shale (with salt water)	12	262	Sandy shale (shell at 785 ft.)	94	795
Clayey shale (2 ft. shell at 275 ft.)	13	275	Sticky sandy shale (second water shut off)	5	800
Clayey shale (no water)	85	360	Sandy shale (considerable water)	118	918
Clayey shale (4 ft. shell at 398 ft.)	85	445			

	Thickness in Feet.	Depth. in Feet.
Sandy shale	64	982
Sandy shale (small streak of white sand with water)	40	1,022
Sandy shale (some clayey shale and sand)	29	1,051
Sandy shale (*with some oil at* 1,070 *and* 1,080 ft.)	49	1,100
Shale (much gas and oil entering)	10	1,110
Sand and shale (much oil)	22	1,132
Shale (carrying oil)	40	1,172
Shale and oil sand (much oil and gas)	53	1,225
Broken shale (much oil)	5	1,230
Shale and oil sand (much oil)	20	1,250
Shale (gas increasing)	18	1,268
Shale and sandy shale (with oil)	28	1,296
Shale (much oil)	12	1,308
Pulverised shale (1,310-1,315 ft., light oil beneath)	11	1,319
Shale (with oil)	19	1,338
Grey shale (strong gas)	4	1,342
Shale	42	1,386
Sandy shale (gas flow heavy; well filled up 400 ft. with mud, water, and oil)	5	1,410
Light-coloured shale (no mud, no oil)	88	1,498
Well filled with oil to 100 ft. of surface	...	1,510
Well commenced flowing	...	1,524
Oil sand (big flow of oil)	43	1,541

Well in Coalinga Oil-Field, California, U.S.A.

(Cable tools.)

	Thickness in Feet	Depth in Feet.
Yellow sand, gravel, and boulders	70	0-70
Yellow sandy clay	105	70-175
Water sand	30	175-205
Yellow clay	25	205-230
Water sand	54	230-284
Blue clay (12½-in. casing to 286 ft.)	11	284-295
Sand	70	295-365
Blue clay	59	365-424
Blue sandy clay	116	424-540
Blue clay	210	540-750
Blue sandy clay	45	750-795
Blue clay	17	795-812
Hard sand	38	812-850
Blue clay	36	850-886
Sand (coarse)	71	886-957
Blue clay	203	957-1,160
Blue clay and shells	10	1,160-1,170
Blue clay	38	1,170-1,208
Shell	4	1,208-1,212
Sand	20	1,212-1,232
Blue clay	20	1,232-1,252
Shell	5	1,252-1,257

	Thickness in Feet.	Depth in Feet.
Blue clay (10-in. casing to 1,369 ft.)	217	1,257-1,474
Shell	10	1,474-1,484
Hard sulphur sand	41	1,484-1,525
Blue clay	20	1,525-1,545
Shell	9	1,545-1,554
Sand and shell	86	1,554-1,640
Blue sandy shale	57	1,640-1,697
Shells (sea shells) (Tamiosoma zone)	4	1,697-1,701
Blue sandy shale	101	1,701-1,802
Shell (8¼-in. casing cemented at 1,802 ft.)	1	1,802-1,803
Blue sandy shale	22	1,803-1,825
Oil sand (fair show of oil and gas)	48	1,825-1,873
Shell	7	1,873-1,880
Oil sand (fair show of oil and gas)	45	1,880-1,925
Blue shale	40	1,925-1,965
Oil sand (good show)	38	1,965-2,003
Black shale (6⅝-in. casing at 2,009 ft. 5 in.)	9	2,003-2,012

Typical Well Section, Baku Oil-Fields of Russia.

(Russian pole tool system.)

	Thickness in Feet.	Depth in Feet.
Upper clay and sand	35	0-35
Blue clay	28	35-63
Sand and small stones	11	63-74
Blue clay (36-in. casing to 88 ft.)	122	74-196
Blue clay with inclined stone	60	196-256
Yellow clay	10	256-266
Water sand with rock	14	266-280
Grey clay	49	280-329
Water sand with rock	21	329-350
Grey sand	42	350-392
Water sand (34-in. casing to 406 ft.)	14	392-406
Sandy clay	35	406-441
Blue clay	29	441-470
Blue sandy clay	14	470-484
Sand and rock	23	484-507
Clay with sandstone	11	507-518
Clay and water sand	3	518-521
Grey sand	52	521-573
Sandstone (inclined)	9	573-582
Sand	2	582-584
Sandstone (inclined)	29	584-613
Yellow clay	38	613-651
Grey sand and rock	47	651-665
Grey sand	47	665-712
Water sand	8	712-720
Water sand and rock	41	720-761
Hard sandstone	10	761-771

	Thickness in Feet.	Depth in Feet.
Blue clay (30-in. casing to 782 ft.)	13	771-784
Yellow clay	101	784-885
Gas sand	50	885-935
Grey water sand	10	935-945
Water sand and rock	27	945-972
Grey sandy clay	51	972-1,023
Water sand and grey sand	13	1,023-1,036
Grey gas sand (28-in. casing to 1,050 ft.)	28	1,036-1,064
Oil sand	7	1,064-1,071
Water sand (26-in. casing to 1,085 ft.)	51	1,071-1,122
Gas sand and blue clay	51	1,122-1,173
Dry gas sand with some oil sand	45	1,173-1,218
Oil sand	15	1,218-1,233
Blue sandy clay (oil)	11	1,233-1,244
Dry gas sand	6	1,244-1,250
Gas sand and oil sand	48	1,250-1,298
Blue clay (24-in. casing to 1,323 ft.)	27	1,298-1,325
Water sand	22	1,337-1,359
Oil sand	14	1,359-1,373
Water sand	25	1,373-1,398
Sandy clay (gas)	51	1,398-1,449
Grey sand	37	1,449-1,486
Variegated clay	11	1,486-1,497
Grey sand	8	1,497-1,505
Water sand and rock	16	1,505-1,521
Water sand } 420 ft. of oil in well	7	1,521-1,528
Gas sand and blue clay }	21	1,528-1,549
Gas sand and brown clay }	16	1,549-1,565
Variegated clay (22-in. casing to 1,582 ft.)	22	1,565-1,587
Blue clay	15	1,587-1,602
Variegated clay	29	1,602-1,631
Clayey oil sand	14	1,631-1,645
Sandy clay	92	1,645-1,737
Oil sand (20-in. casing to 1,757 ft.)	25	1,737-1,762
Blue clay	23	1,762-1,785
Blue marly clay	8	1,785-1,793
Oil sand (18-in. casing)	27	...

Cemented between 34-in. and 24-in. casings and between 18-in. and 24-in. to exclude water. Production 100-150 tons daily.

Typical Well in the Grosny Oil-Field of Russia.

(American cable system or Russian pole tool.)

	Thickness in Feet.	Depth in Feet.
Surface sand	...	0-10
Yellow clay	37	10-47
Grey clay (24-in. pipe stopped at 50 ft.)	314	47-361
Limestone	3	361-364

	Thickness in Feet.	Depth in Feet.
Grey clay - - - - - - - - -	134	364-498
Dolomite (so-called—a hard stone) - -	2	498-500
Grey clay - - - - - - - - -	2	500-502
Grey clay and dolomite - - - - -	10	502-512
Grey clay - - - - - - - - -	6	512-518
Grey clay, dolomite stone, and water - -	12	518-530
Grey gassy clay - - - - - - -	4	530-534
Brown clay and dolomite - - -	14	534-548
Brown clay - - - - - - - - -	10	548-558
Brown clay and dolomite - - - -	12	558-570
Limestone - - - - - - -	2	570-572
Grey clay and dolomite - - - - -	18	572-590
Brown clay - - - - - - - -	4	590-594
Grey gassy clay, with exhausted oil sand -	3	594-597
Clay, with oil sand - - - - - - -	11	597-608
Dark grey clay and oil sand - - - -	10	608-618
Brown clay and stone - - -	4	618-622
Dark grey clay - - - - -	12	622-634
Brown clay and sand - - - - - -	14	634-648
Grey clay - - - - - - - - -	9	648-657
Green sandy clay - - - - - -	12	657 669
Grey clay and sand - - - - - -	11	669-680
Brown clay - - - - - - - - -	19	680-699
Grey sandy clay (20-in. pipes stopped at 706 ft.) - - - - - - - -	11	699-710
Brown clay and sand - - - - - -	10	710-720
Grey clay and sand - -	10	720-730
Brown clay - - - - - - -	14	730-744
Grey clay - - - - -	14	744-758
Green sandy clay - - - - - - -	8	758-766
Green sandy clay, with calcite - -	5	766-771
Oil sand - - - - - - - -	4	771-775
Green sandy clay - - - - - - -	13	775-788
Grey clay and calcite - - -	7	788-795
Dark grey sandy clay - - - - - -	4	795-799
Grey sand - - - - - -	9	799-808
Dark grey oil sandy clay - - - -	5	808-813
Brown clay and sand - - - - - -	31	813-844
Grey clay and oil sand - - - - - -	16	844-860
Brown sandy clay - - - - - - -	3	860-863
Clay and grey oil sand - - - -	11	863-874
Brown sandy clay (16-in. pipes stopped at 885 ft.) - - - - - - - -	27	874-901
Grey clay and stone - - - -	3	901-904
Grey clay and sand - - - - - -	7	904-911
Brown clay - - - - -	3	911-914
Grey clay and stone - - - - - -	6	914-920
Grey clay and oil sand - - - - - -	30	920-950
Grey clay and stone - - - - -	6	950-956

	Thickness in Feet.	Depth in Feet.
Brown clay and sand	7	956-963
Grey clay and sand	15	963-978
Brown gassy clay	3	978-981
Green clay and stone	3	981-984
Brown clay	3	984-987
Clay and oil sand	7	987-994
Grey clay and sand	8	994-1,002
Brown clay	35	1,002-1,037
Grey clay	1	1,037-1,038
Grey clay and oil sandstone	21	1,038-1,059
Brown clay and sand	2	1,059-1,061
Brown clay	35	1,061-1,096
Brown clay and stone	6	1,096-1,102
Brown clay	18	1,102-1,120
Brown clay and stone	20	1,120-1,140
Grey gassy clay and sand	18	1,140-1,158
Brown clay	28	1,158-1,186
Grey clay, with exhausted oil sand	10	1,186-1,196
Grey gassy clay	12	1,196-1,208
Brown clay and oil	18	1,208-1,226
Brown clay and stone	2	1,226-1,228
Brown clay and sand	13	1,228-1,241
Brown clay and stone	2	1,241-1,243
Dark grey clay and stone	6	1,243-1,249
Dark grey clay	6	1,249-1,255
Dark grey clay and oil sand	3	1,255-1,258
Brown clay and sand	14	1,258-1,272
Grey gassy clay and exhausted oil sand	6	1,272-1,278
Brown clay and sand	5	1,278-1,283
Brown clay and sandstone	10	1,283-1,293
Brown clay	15	1,293-1,308
Brown clay and stone	13	1,308-1,321
Yellow stone	2	1,321-1,323
Brown clay and stone	8	1,323-1,331
Brown clay and exhausted oil sand	12	1,331-1,343
Brown clay and sand (14-in. pipe stopped at 1,344 ft.)	3	1,343-1,346
Grey clay and oil sand	2	1,346-1,348
Oil sand	25	1,348-1,373
Grey gassy clay and sand	1	1,373-1,374
Oil sand (not very productive)	6	1,374-1,380
Brown clay and stone	4	1,380-1,384
Oil sand	15	1,384-1,399
Grey clay	15	1,399-1,404
Brown clay	16	1,404-1,420
Brown clay and stone	12	1,420-1,432
Grey clay and green sand and stone	6	1,432-1,438
Brown clay	25	1,438-1,463
Grey sand and water	27	1,463-1,490

	Thickness in Feet.	Depth in Feet.
Brown sandy clay	13	1,490-1,503
Dark grey clay and sand	6	1,503-1,509
Brown clay and sand	11	1,509-1,520
Brown clay and stone	3	1,520-1,523
Brown clay and sand	7	1,523-1,530
Dark grey clay and sand	15	1,530-1,545
	11	1,545-1,556
Brown clay	5	1,556-1,561
Brown clay, sand, and stone (10-in. pipe stopped at 1,592 ft.)	26	1,561-1,587
Brown clay	19	1,587-1,606
Green clay and sand	9	1,606-1,615
Grey gassy clay and oil sand	5	1,615-1,620
Oil sand (good production)	5	1,620-1,625
Brown clay	13	1,625-1,638
Brown clay and oil	12	1,638-1,650
Oil sand	53	1,650-1,703
Brown clay	37	1,703-1,740
Brown clay and stone	4	1,740-1,744
Oil sand	11	1,744-1,755
Grey clay and oil sand	45	1,755-1,800
Brown clay and oil	23	1,800-1,823
Brown clay and stone	25	1,823-1,848
Brown clay and sandstone	4	1,848-1,852
Brown clay and sand	12	1,852-1,864
Brown clay and oil	16	1,864-1,880
Brown clay, oil, and stone	9	1,880-1,889
Brown clay and oil sand	7	1,889-1,896
Brown clay and oil	34	1,896-1,930
Grey clay and stone	8	1,930-1,938
Grey clay and sand	4	1,938-1,942
Grey clay, green sand, and stone	3	1,942-1,945
Grey gassy clay and oil	14	1,945-1,959
Brown gassy clay and oil	5	1,959-1,964
Hard sandstone	5	1,964-1,969
Brown gassy clay	16	1,969-1,985
Brown gassy clay and oil sand	9	1,985-1,994
Brown gassy clay	5	1,994-1,999
Oil sand (big flow of oil; flowed for weeks unaided; depth of hole 2,037 ft., 8-in. pipes to 1,988 ft.)	3	1,999-2,002

Typical Well in the Tustanowice Oil-Field of Galicia.

(Production about 380 tons daily.)

	Thickness in Feet.	Depth in Feet.
Clay (17-in. casing to 87 ft.)	98	0-98
Shale (15-in. casing to 98 ft.)	33	98-131
Clay (13½-in. casing to 182 ft.)	460	131-591
Shale (12-in. casing to 246 ft.)	98	591-689

	Thickness in Feet.	Depth in Feet.
Clay (10-in. casing to 774 ft.; water shut out)	124	689-813
Laminated clay and shale	399	813-1,212
Clay	63	1,212-1,275
Laminated clay and shale	52	1,275-1,327
Shale	102	1,327-1,429
Laminated clay and shale	81	1,429-1,510
Sandstone	13	1,510-1,523
Laminated clay and shale	67	1,523-1,590
Shale	110	1,590-1,700
Clay	7	1,700-1,707
Shale	25	1,707-1,732
Laminated shale and sandstone	73	1,732-1,805
Shale	171	1,805-1,976
Laminated clay and shale	42	1,976-2,018
Shale	44	2,018-2,092
Sandstone	8	2,092-2,070
Shale	6	2,070-2,076
Sandstone	32	2,076-2,108
Laminated shale and sandstone	74	2,108-2,182
Clay	8	2,182-2,190
Shale	6	2,190-2,196
Laminated shale and sandstone (9-in. casing to 2,204 ft.)	37	2,196-2,233
Shale	49	2,233-2,282
Clay	10	2,282-2,262
Shale	33	2,292-2,325
Laminated shale and sandstone	96	2,325-2,421
Shale	70	2,421-2,491
Laminated clay and shale	49	2,491-2,540
Laminated shale and sandstone	85	2,540-2,625
Shale	78	2,625-2,703
Sandstone	7	2,703-2,710
Shale	43	2,710-2,753
Sandstone	7	2,753-2,760
Shale	50	2,760-2,810
Clay	4	2,810-2,814
Shale	37	2,814-2,851
Sand with gas	4	2,851-2,855
Shale	65	2,855-2,920
Sand	12	2,920-2,932
Shale	68	2,932-3,000
Sandstone	10	3,000-3,010
Shale	7	3,010-3,017
Sandstone	25	3,017-3,042
Shale	3	3,042-3,045
Sandstone	37	3,045-3,082
Clay	5	3,082-3,087
Sandstone	13	3,087-3,100

	Thickness in Feet.	Depth in Feet.
Shale	23	3,100-3,123
Sandstone	7	3,123-3,130
Clay (caving)	32	3,130-3,162
Sandstone	21	3,162-3,183
Clay	17	3,183-3,200
Shale	61	3,200-3,261
Sandstone	7	3,261-3,268
Shale	62	3,268-3,330
Sandstone	7	3,330-3,337
Shale	42	3,337-3,379
Laminated clay and shale	41	3,379-3,420
Sandstone	40	3,420-3,460
Shale	62	3,460-3,522
Sand (oil at 3,540 ft.)	38	3,522-3,560
Laminated shale and sand (caving; $7\frac{5}{8}$-in. casing to 3,640 ft.)	212	3,560-3,772
Shale	128	3,772-3,900
Laminated shale and sand (oil at 3,972 ft.)	68	3,900-3,968
Shale	32	3,968-4,000
Laminated shale and sand ($6\frac{5}{16}$-in. casing to 4,150 ft.)	160	4,000-4,160

Typical Wells in Negritos Oil-Fields of Peru.

(Casing perforated at various oil sources. Manila cable system of drilling.)

	Thickness in Feet.	Depth in Feet.
Grey shale (some oil at 220 ft.)	770	0-770
Oil sand (good oil source)	20	770-790
Grey shale	55	790-845
Oil sand (oil rose 600 ft. in well)	35	845-900
Grey shale	658	900-1,558
Oil sand (well flowing)	78	1,558-1,636

Grey shale	265	0-265
Oil sand with oil	10	265-275
Grey shale	275	275-550
Oil sand with oil	20	550-570
Grey shale	150	570-720
Oil sand (well flowing)	25	720-745

Initial productions, 20-30 tons daily.

Typical Canadian Well (Petrolia and Oil-Springs District).

(Wire rope cable or Canadian tools.)

	Thickness in Feet.	Depth in Feet.
Blue clay	70	0-70
Upper limestone	50	70-120
Upper soapstone	150	120-270
Middle limestone	20	270-290
Lower soapstone	30	290-330
Lower limestone (with oil)	100	330-430

Deep Canadian Well to Trenton Limestone.

	Thickness in Feet	Depth in Feet.
Clay	60	0-60
Gravel	5	60-65
Black shales	85	65-150
Limestone	15	150-165
Soapstone	205	165-370
Limestone	25	370-395
Soapstone	25	395-420
Corniferous limestone—black sulphurous water at 500 ft. in Petrolia oil-bearing rock	115	420-535
Dolomite, limestone, and marls, with gypsum and rock-salt. Red rock-salt, 1,410-1,655 ft.; red rock-salt, 1,810-1,835 ft	1,300	535-1,835
Limestone dolomite	225	1,835-2,060
Dark shales (Niagara)	15	2,060-2,075
Limestone (Clinton)	35	2,075-2,110
Red shales (Medina) and light grey shales with limestone	440	2,110-2,550
Shales (Hudson River)	285	2,550-2,835
Dark shales	175	2,835-3,010
Trenton limestone (only oil and gas bearing in places)	380	3,010-3,390

CHAPTER IV.

INDICATIONS OF PETROLEUM AND PHENOMENA ASSOCIATED WITH ITS OCCURRENCE.

Surface Indications of Petroleum — Evolution of Gas — Mud Volcanoes — Petroleum Seepages and Asphalt Deposits — Bituminous or Asphaltic Rocks—Native Bitumens—Ozokerite—Saline and Sulphurous Waters—Oil Shales—Interpretation of Surface Indications—Prospecting for Petroleum.

Surface Indications of Petroleum.—The physical characteristics of petroleum-bearing regions vary widely in different countries. Prevalence of petroleum not uncommonly exerts a marked influence upon the topography of a district as a consequence of its injurious influence upon vegetation, but this latter is influenced to a great extent by the geographical situation of the locality, and the frequency and amount of rain or prevalence of long droughts. In rainless or nearly rainless tropical countries, the presence of petroleum and other injurious compounds which usually accompany oil have a very pronounced effect, and are often a contributory cause of many square miles of barren waste. In tropical and sub-tropical countries where abundance of rain falls, especially in hilly districts where the water rapidly flows away, the vegetation is little affected by the prevalence of petroleum-permeated beds; but in other districts where the rainfall is small, the vegetation is often of a stunted character, if present at all. In many of the dense tropical jungles of Borneo and Sumatra in the East, and of Central America and Trinidad in the West, where oil conditions prevail, the wild vegetation seems to flourish unchecked amidst a mass of bituminous matter and in quagmires of oily slime; even the famous pitch lake of Trinidad, although composed largely of solid asphalt, is not devoid of vegetable growth, for dotted over its surface are tufts of coarse grass and low scrubby bushes, that maintain a bare existence on particles of soil attached to the pitch. Bare, barren wastes

characterise the oil-fields in the almost rainless regions of Upper Burma, Persia, Egypt, Algiers, and Peru, as well as many of the Russian oil districts, and some of the western fields of the United States.

The presence of petroleum in the rocks of a district is not always indicated by any outward signs which would give the least clue to a casual observer. Many of the oil-fields of the world owe their discovery to the casual striking of oil in wells sunk for water, or during searches for brine, which is commonly associated with oil. Drake's original well at Oil City was sunk amidst brine wells, and as recently as 1908 a rich find of oil resulted from the drilling of a water well in the Argentine Republic, at Comodore Rivadavia, by the Government of that country. In some regions there are seepages of crude oil which intimate the existence of supplies beneath the surface, and occasionally the issuing oil is allowed to accumulate in pools, from which it is periodically removed. On two occasions, in the years 1908-9, great quantities of petroleum suddenly issued from cracks in the ground along the Trans-Caucasian Railway, where oil-bearing strata occur; and in the later case, near Aliat railway station, it was said that the oil flowed in such quantities that large lakes of oil were formed on the surface, inundating the railway line for some distance. The varied phenomena attending the distribution of petroleum will be described and explained in detail in the following pages.

The predominance of unconsolidated plastic clays and clay-shales, that especially characterise oil-fields of Tertiary age, results in a form of weathering that is repeated in many far distant regions. Amidst such surroundings disintegration proceeds at a rapid rate, especially under the influence of rains and frequent landslides, and heavy mud greatly impedes normal operations during wet seasons. There is an extraordinary resemblance in such far-separated fields as Roumania, Galicia, Russia, Burma, Peru, and California.

In the neighbourhood of some oil-fields massive outcrops of sand, stained or even saturated with oil, bear eloquent testimony to their importance as possible sources of petroleum. Around the

Baku and Maikop oil-fields of Russia, and amidst the Californian, Peruvian, Trinidadian, and Roumanian oil-fields may be observed extensive outcrops of oil-soaked rocks, that afford exceptional facilities for scientific study.

Heavy asphaltic oils usually transmit a dark discoloration, and impart a stickiness to the grains that causes them to resist weathering, and often to stand out in bold relief in sections. Sands impregnated with less dense petroleum often assume a slight discoloration, not unlike in appearance an iron-stained sandstone, and there may be no obvious trace of oil. Doubts can be removed by agitating a crushed sample in water or benzine, and noting the extract. A specimen of sand placed on blotting-paper will often produce a grease stain. The weathered edges of oil sands often betray little evidence of oil, as they have suffered oxidation and have become bleached. Outcropping oil strata sometimes yield a wealth of efflorescences in which sodium chloride and sulphate, alum, carbonate of lime, and other salts participate. Sometimes a hard incrustation is formed on the surface, but usually light flocculent growths occur, crystallisations from water drawn by capillary attraction from the strata. Sufficient salt is leached from low-lying out-cropping strata by winter rains in valleys around the Baku oil-fields to yield large supplies of salt by solar evaporation in the dry season.

Evolution of Gas.—Whilst natural inflammable gas is not by any means a positive indication of the existence of petroleum, its association with that mineral is so general in all parts of the world, that it is impossible to disregard its presence if it occurs in a district where there is other confirmatory evidence, or the geological conditions are favourable. Not infrequently natural gas originates from causes quite different from those attending the formation of petroleum, while in other cases it accumulates in porous strata not directly communicating with oil beds, although it has been derived from them ; but if there is a petroliferous or "paraffin" odour, the origin of the gas should be investigated and established before rejecting the idea of its association with petroleum. The escape of gas cannot be readily detected in dry, barren districts, but it is usually recognised by an odour

ervading well-sheltered ravines, or by bubbles of gas rising from uddles of water or beds of streams. On applying a light to the scaping gas combustion takes place, and if the supply of gas is teady, it will continue to burn with a slightly luminous, semi-ransparent flame. In marshy ground, or stagnant pools, a imilar escape of gas (methane or marsh gas) can often be bserved, especially in warm weather, if the mud is stirred, but his is merely a product of decomposing vegetation, and quite listinct from that originating from petroleum. As is well known, he moving, feebly luminous flame of marsh gas sometimes occurring over treacherous marshy ground is commonly called the 'Will o' the Wisp." Petroleum gas generally contains from 80-90 per cent. of methane, but there are other hydrocarbons present which impart to it a distinctive odour, and these simplify its recognition as petroleum gas.

Although petroleum gas can generally be distinguished by its odour, it is sometimes contaminated to such an extent with gases of a more pungent odour that its qualities are masked. Both sulphur dioxide and sulphuretted hydrogen, as well as carbon dioxide and nitrogen, are commonly associated with petroleum gas, and the two former entirely disguise the pétroleum odour at times. Small quantities of gas may continually escape through crevices and fault fissures from a considerable depth, and thus indicate the possible existence of an oil or gas stratum far below the surface; but usually the apparent gas exudations, often developed on a large scale, occur where there is a fractured crest of an anticline, or where the strata are inclined, and the edges of the petroleum-bearing or gas-producing beds either outcrop at the surface, or are covered only by a superficial layer of over-burden. Usually the gas exudes slowly, but fairly constantly, from numerous points over a large area; at other times there are prolonged periods of quiescence between successive eruptions. The gas only occasionally escapes with sufficient continuity, and in large enough volume to burn constantly if ignited, but at times such is the case, and gas exudations, which have been accidentally lit or have fired spontaneously have continued to burn for years. On the ridge of hills fringing the Poota Valley, near

Baku, there is an area of about an acre where the escaping gas is rarely, if ever, extinguished, and in the Yenangyat district of Burma a somewhat similar phenomenon is observable at Yenang Daung. The gas appears to escape from numerous fissures in the strata, causing a large number of sheets of flame to rise to the height of a foot or two above the surface of the ground.

In the Surakhany district of the Baku oil-fields, the fire of the natural gas has been an object of worship for some 2,500 years, and it was only about 1898 that annual pilgrimages to a temple in the district were suppressed by the Russian Government. Throughout the Surakhany area the gas has for many years been used by the peasants for burning limestone, which occurs locally. Ample supplies of gas were till recently obtained by excavating 20-50 ft. into the dark, fine-grained sands of that region. The development of this region for oil and gas has practically exhausted the upper beds.

In some petroleum regions the gas only bursts forth at distant intervals of time, the district in the intervening period exhibiting no indications of petroleum or gas. Such phenomena are frequent in the East and West Indian oil-fields, and in the Caucasian oil belts fringing the Baku oil-fields. In the Poota and Binagadi districts near Baku there are several mounds which display violent activity occasionally. From one hill of more than ordinary fame, which, however, would not attract a casual observer's attention at ordinary times, the gas occasionally bursts forth in immense volumes through numerous rents blown in the side, and the heat emitted by the burning gas, which ignites spontaneously, is intense. The glare is distinctly visible from Baku, 10-12 miles away, and the spectacle usually attracts a number of sight-seers. On two occasions when the author was in Baku this particular hill was in eruption, once in 1898 and again in 1904, but many years often elapse between successive eruptions. An examination of the hill after the few days' activity had ceased revealed unmistakable evidence of the intensity of the discharge, as cavities large enough to admit the body of a man were blown in the side of the hill, whilst the burnt nature of the material forming the hill testified to the great heat developed. In 1902

an eruption of gas, which also spontaneously ignited, caused the destruction of a herd of sheep grazing on the scrub in the Kir-Maku district, to the west of Zabrat, Baku.

Severe seismic shocks usually influence the escape of gas, and many of the great evolutions recorded in literature have been coincident with earthquakes. In the calamitous earthquake of 1902, when the town of Schemakha, in the Caucasus, was destroyed, great consternation was aroused by the issue of inflammable gases from numerous fissures which appeared in the earth, the district being petroliferous in character.

Caucasian peasants often utilise the natural gas for cooking and lighting, by improvising stoves over crevices from which petroleum gas issues, when, to induce a large volume of gas to flow towards their stove, they often insert a short piece of piping into the crevice, and make a clay puddle round the top of the tube to direct the gas into the tubing.

Gas exudations are not confined to the land; they occur just as frequently in lakes, rivers, and seas. Some excellent examples of submarine exudations are found in the Caspian Sea, and off the coasts of Burma and Borneo, where the oil-producing strata extend. It is said that at one time a light applied to the sea in Baku Bay, on a calm day, would result in acres of flame, but the active development of the Baku oil-fields has caused a diminution of such phenomena, although there were in 1910 several spots off Bibi-Eibat, near Baku, where the gas was evolved in sufficient volume to cause the water to be violently agitated in the vicinity. A piece of lighted tow thrown into these patches would ignite the gas. In the presence of a stiff breeze the flame is blown aside and extinguished, although on a calm day the gas continues to burn vigorously. Old inhabitants assert that gas escaped with such violence at one time near Bailoff that boats were capsized if incautiously allowed to approach too near. Near Holy Island, in the Caspian, there are similar exudations of gas from beneath the sea, they, likewise, resulting from the continuation of the oil-bearing beds seen on the island. There are many localities in the Caribbean Sea, off the coast of Mexico, where vast quantities of oil are periodically ejected, covering the sea for miles; and off

the coast of Texas, near Sabine Pass, there are several well-known localities known as "oil ponds," where the sea is always calm, and where coasting vessels seek shelter during storms. These oil ponds are less than a mile in diameter, and the reason seas never break there is attributed to exudation of petroleum from submarine springs.[1]

The author has observed the escape of gas in the sea off the coast of Peru, where there are well-defined oil-bearing beds on the shore, and sometimes the odour of petroleum gas is very pronounced in the breezes from the sea. Violent submarine eruptions have been reported off the coasts of Burma and the Klias Peninsula in Borneo, evidently attributable to the issue of petroleum gases following disturbance. Off Galeota Point, on the south-eastern corner of Trinidad, submarine eruptions have been recorded, accompanied by a great discharge of petroleum and pitch, which spread over the sea; and in the Gulf of Paria similar outbursts have caused a destruction of fish. The violent explosions, which were attributed to volcanic action, occasioned much consternation amongst the natives, who asserted that a column of water rose from the sea to a considerable height at the moment of the explosion, and that the coast line for many miles was strewn with pitch and petroleum.

Other gases which are frequently to be found escaping from the ground in oil regions are carbon dioxide, sulphur dioxide, and sulphuretted hydrogen. The carbon dioxide is not easy to discover, as it is an inodorous, non-inflammable, and invisible gas. Sulphur dioxide, easily detected by its pungent sulphurous odour and its stinging effect upon the nose, can often be traced in oil-bearing regions. It is prevalent in the districts around Baku where the oil strata approach the surface, and it has been observed in the Texan and Californian oil-fields. The gases accompanying the oil on Spindle Top, Texas, were exceedingly poisonous through association with sulphur gases, and many deaths resulted from inhalation. Sometimes the escape of sulphur dioxide from fissures leads to a sublimation of pure yellow sulphur

[1] See United States Geological Survey, "Report on Texas Oil Fields in 1903," by Hayes and Kennedy.

PLATE XX.

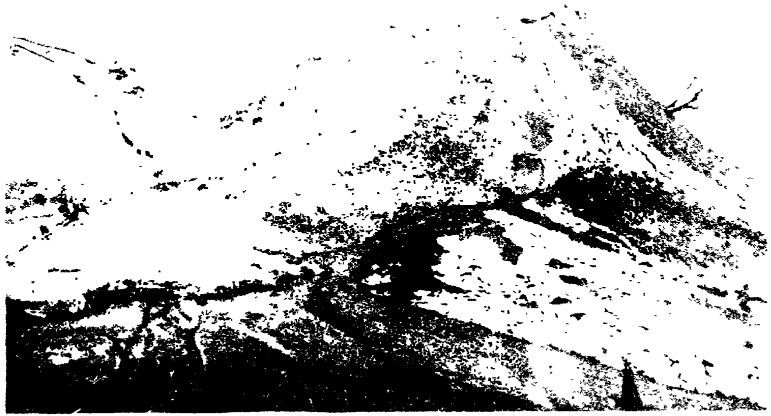

FIG. 18.—MUD VOLCANO NEAR LAKE TOTUMA, COLOMBIA.

This is connected with a much larger though less conspicuous mud volcano.

[To face page 180.

around the crevices from which the gas issues, a result which may be due either to a chemical reaction between sulphur dioxide and sulphuretted hydrogen, resulting in the production of water and sulphur or in incomplete oxidation of sulphuretted hydrogen. Escaping sulphuretted hydrogen can often be detected in the vicinity of oil outcrops by its disagreeable odour, a property which renders its recognition easy.

These poisonous gases, either singly or commingled, occasionally collect in natural depressions, where, undisturbed by winds, they form deadly pits in which wild animals or men are apt to be asphyxiated if they incautiously stray. Such treacherous places are known in the United States, Cuba, and elsewhere, the localities often being marked by a collection of bones of birds and animals which have unwarily ventured into these traps and met their doom. In the Caucasus there are valleys where, in the heat of summer and during the absence of a breeze, the air becomes so charged with these gases that a sensation of oppression and nausea is produced if one lingers too long in them.

Many oil wells yield an abundance of both sulphuretted hydrogen and sulphur dioxide.

Mud Volcanoes.—One of the most common phenomena associated with the presence of petroleum is the mud volcano. Mud volcanoes result from the evolution of natural gas through soft strata impregnated with water, which has either been admitted into the surface alluvium or was present in the beds from which the gas is evolved. If oil or gas bearing beds are covered by clays or recent alluvium, which is either insufficiently thick to restrain the gas pressure below, or becomes fissured by earth movements or landslides, gas escapes, and if water is present a mud is brought to the surface and deposited in a circle around the point of issue. In course of time the constant ejection of mud and evaporation of the moisture leads to the formation of conical mounds, through the centre of which a channel is kept open for the passage of gas and mud. Continuous action in districts not frequented by heavy rains causes the growth of hills a hundred, and even several hundred, feet high which become landmarks in the district (see Fig. 18,

Plate XX.). Such mud volcanoes are to be seen on an exceptionally large scale in Russia around the Baku oil-fields, in the Kuban district near the Black Sea, and in the Taman Peninsula, where great streams of mud may be observed flowing down their sides. They abound in the Borneo and Sumatra oil-fields, and the Arakan Islands off the coast of Burma, and good examples may be seen in Colombia, Roumania, and Trinidad. The larger hills are usually the result of the combined action of a number of smaller volcanoes, and the summits will generally be found to be strewn with a number of small craters, and rarely a large single crater, from whence the mud and gas escape.

So common is the phenomenon to which the term mud volcano has been applied that there are few Tertiary oil-fields in the neighbourhood of which they are quite absent. Naturally they are more prevalent where the oil beds closely approach the surface on an anticline, or where steeply inclined outcrops of oil strata lie covered by or associated with soft clays, but they are often quite absent where oil beds lie at a great depth below the surface, or where the surface stratum is of too compact a nature to form cones of mud.

Mud volcanoes are to be seen on an unusually large and interesting scale in the southern section of the island of Trinidad, and some of the larger ones become extremely violent at intervals, and even cause damage. A house on the Colombia Estate at Cedros was rendered almost uninhabitable by an upheaval from a mud volcano near by, and at other spots where they occur acres of agricultural land have been thrown into disuse by ejections of mud and oil. In February 1906 the author was fortunate enough to witness the eruption of one of the largest and most famous of the Trinidad mud volcanoes near Cedros, and secured a number of interesting photographs. Several acres of ground were quite bare of vegetation, and strewn with newly-ejected, well-puddled, argillaceous material mixed with occasional fragments of iron pyrites, flints, and pieces of lignite. Around this area inflammable gas was oozing up through numberless fissures with a hissing sound, and towards the centre was a crater of stiff pasty clay, kept in agitation and puddled by the

PLATE XXI

FIG. 10. LARGE MUD VOLCANO IN ERUPTION, TRINIDAD.

Many thousand tons of puddled clay were ejected in a few hours, accompanied by the evolution of hundreds of thousands of cubic feet of inflammable gas.

[*To face page* 182.

evolution of immense volumes of gas. This central crater had a diameter of about 60-80 ft., and the discharged mud was so soft around that close approach was unsafe. At intervals of a few minutes violent eruptions occurred, accompanied by the evolution of enormous volumes of gas, causing the ejection of many tons of clay to a height of 20-30 ft. Before each explosion the ground for a radius of 50 ft. heaved and quivered, and the central portion rose slowly until it burst, causing the expulsion of masses of clay, the bulk of which fell back into the crater in great blocks.

Where water is present in large quantities mud volcanoes do not display the same violence, as the well-mixed mud is kept thin by constant agitation, allowing the gas to escape more freely through the fluid mass at any point. In another case the author made an estimate of material ejected in less than one hour, and found the quantity to exceed 35,000 cub. yds. spread over an area of several acres. Large cracks opened up in the ground over an area of many acres.

On the 21st December 1897 the di turbance occasioned by an earthquake led to the formation of a great mud volcano beneath the sea off the southern point of the Klias Peninsula of Borneo, when sufficient argillaceous material was ejected to form a new island 750 ft. long, 420 ft. wide, and 20 ft. above sea-level. The eruption occurred on the crest of a well-known anticline with steep sides, on which petroleum and gas exudations had frequently been observed in other localities where it crossed the land.[1]

Some renowned mud volcanoes exist on the Arakan Islands off the coast of Burma, and they often display unusual activity when an earthquake disturbs the inclined oil and gas bearing strata which occur in that region. Probably one of the greatest mud volcanoes on record was formed off the Burma coast on 15th December 1907, when sufficient material was ejected to form an island 1,200 ft. long, 600 ft. wide, and 20 ft. above sea-level, upon which a landing was effected by the

[1] J. A. Stigand gives the initial height as 50-60 ft., and states that the island eventually became joined to the mainland by accumulations of sand.

officers of a British marine survey ship shortly after the eruption, when the mud still indicated a temperature of 148° F. a few feet below the surface.

An exceptionally violent eruption occurred off Erin, on the southern coast of Trinidad, on 4th November 1911. Masses of material were observed being ejected from the sea, accompanied by enormous volumes of gas, which became ignited, and considerable noise. The flames could be seen many miles away as they rose to a height of a hundred feet or more. An island was noticed to be steadily rising from the sea as the material increased in quantity, until after several hours of activity it had an area of 2½ acres and was 14 ft. above sea-level at its highest point.

On cessation of activity the island was visited next day by a party who discovered the material to be the usual puddled clay mixed with some particles of rock: the temperature of the mud was sufficiently high to make a visit uncomfortable. This eruption occurred on the crest of a known anticline that could be traced both eastward and westward on the land, and fishermen had noticed the ascending bank a day before the great eruption.

Petroleum Seepages and Asphalt Deposits.—Natural issues of petroleum obviously afford the most positive evidence of its occurrence, and it is amidst their occurrences that most of the Tertiary oil-fields of the world are located. Their nature and extent act as a guide in estimating the economic importance of a deposit, and frequently provide the sole clue to the occurrence of petroleum in a district. Oil exudations cannot be mistaken, as a few simple tests settle any doubts; yet it is surprising how many times the easily distinguished, iridescent, oily-looking film of oxide of iron on chalybeate waters has been taken for oil. An extremely small seepage of oil will reveal its presence upon a surface of water, as owing to its low surface tension a particle spreads into a fine film over a large area. Concealed oil sources are often disclosed by particles of oil, raised with ascending waters, accumulating on pools or sheltered by-washes of streams. Petroleum unaccompanied by water may ooze from exposed beds, or issue from crevices in covering clays, and in some localities

FIG. 20.—LARGE MUD VOLCANO IN DENSE JUNGLE.

FIG. 21.—TYPICAL MUD VOLCANOES OF ORDINARY DIMENSIONS.

[*To face page* 184.

gallons or even barrels of oil may be daily recovered in a suitably placed receptacle. Peasants frequently obtain supplies from pools by drawing a cloth over the surface oil, and then wringing its absorbed contents into a vessel.

Seepages sometimes reach a considerable magnitude where oil beds outcrop, and they then become the seat of a native industry. Most Tertiary oil districts yield numerous examples. Light oil seepages leave less trace of their presence than the heavier types, but occasionally, as at Lizard Spring, Trinidad, great quantities of light oils issue and accumulate in neighbouring depressions. When the topography is favourable or the climate or grade of oil suitable, escaping oils quickly suffer loss of volatile constituents, become oxidised and converted into semi-solid pasty masses of asphalt that are not readily washed away, and in time reach large dimensions. Around many of the known oil-fields there are extensive deposits of these oxidised products of petroleum, etc.

In hot, dry regions, where vegetation is scarce, particles of sand or dust soon attach themselves to the sticky pitch, and produce a solid material of limited commercial worth on account of the large percentage of extraneous matter that has to be artificially extracted before the pitch constitutes a valuable article of commerce. Where the oil oozes from outcrops on the side of the hills, deposits of contaminated pitch will often be found in the surrounding low-lying districts, but in very hilly districts all traces may be removed by rains, which carry everything into the neighbouring streams. When the less volatile constituents of petroleum accumulate in a forest or tropical jungle, the pitch will always be found to contain a large quantity of carbonaceous matter, such as fragments of wood and leaves, which are preserved from decomposition. Insects, animals, and birds which stray into the more liquid pitch are often engulfed, and their remains are perfectly preserved for long periods. Attention is directed by the United States Geological Survey to the large number of well-preserved remains of extinct animals that are to be found in the "tar springs" of the Los Angeles district of California, the larger animals having apparently been lured into these deposits

by smaller animals and birds already caught and unable to escape.[1] Likewise in Peru the author discovered some pitch deposits in which there was an abundance of bones of large animals that had evidently become bogged, and their remains preserved; and on Holy Island in the Caspian similar remains have been observed.

It will generally be observed that the petroleum does not exude from the whole line of outcrops as one might have surmised, but escapes from a larger or smaller number of conical mounds which are distributed along the strike of the outcropping oil rock. Such a condition seems to be due to two causes: firstly, the solidified asphalt forms, after a time, a hard covering through which further oil cannot thrust its way without some exertion of force, thus leading to the escape of the oil from other points of weaker resistance which continue to be so unless they become choked by some obstacle; secondly, there is a tendency towards the formation of definite channels by the escaping oil, which, after centuries of action, are not readily deflected into new directions. Both actions bring about the formation of conical mounds of asphalt, from the centre of which the petroleum either constantly or intermittently exudes from small craters and flows down the sides. The existence of such channels through which the oil flows by preference is supported by the common occurrence of fine sand with the oil, the conclusion being that this represents particles of rock detached from the bed by the oil during its slow progress outwards.

Asphaltic deposits are often very deceptive in their appearances, and a far greater importance may be attributed to them than they deserve. Masses covering an area of an acre or more may be traced to a single or several small exudations from joint cracks or fissures, the asphalt constituting the accumulation of long periods, and covering a large surface with a mere capping.

In some parts of the Caucasus there are hills of asphalt, many feet in height, through which a heavy, black asphaltic oil still exudes from numerous points in all directions. So soft are some of these that they will not sustain the weight

[1] Bulletin No 809, United States Geological Survey, 1907.

of a man, notwithstanding the addition of a large percentage of siliceous matter which has attached itself to the pitch and rendered it harder. An outcrop of the Baku oil sands on the edge of the famous Balakhany oil-field is indicated by a hill of asphalt mixed with mud and sand over 100 ft. high, and notwithstanding the active development of the district, indeed almost the exhaustion of that particular region, oil and gas with some mud still ooze up from numerous little cones. On one side of this hill, known as Bog-boga, the removal of surface sand has exposed a rich deposit of solid pitch (*kir*) which is largely extracted by the Tartar peasants for the manufacture of asphalt for paving and roofing purposes. On Holy Island, in the Caspian, the surface soil exposes great deposits of pitch, the accumulated residuum of thousands of tons of petroleum which have been expelled from the oil rocks and subjected to atmospheric influence.

Extensive deposits of asphalt exist in Russia, California, Trinidad, Venezuela, Cuba, Mexico, Borneo, West Africa, and other places, and these have often been worked to supply the ever-increasing demand for various qualities of this material for road-making, electrical insulation, waterproofing, etc., etc. The renowned pitch lake of Trinidad has been the subject of speculation ever since it fell into the possession of the British, yet its origin is as obvious as the smaller deposits of somewhat similar material in other parts of the world. A brief description of this well-known and often-described lake may be of interest, especially as it has for many years been the chief source of asphalt for the world.

The Trinidad Pitch Lake, which takes the form of a rough circle, and has an approximate area of 127 acres, is situated about a mile inland from Brighton, where a pier has been erected to simplify the loading of steamers. The surface of the lake is practically level, except for a peculiar series of depressions which in reality are folds or wrinkles resulting from slow movements of the main mass as pitch is extracted from the outskirts; but it is quite hard and impervious to water, and its surface has the peculiar, fine, wrinkled appearance that one always associates with drying pitch.

Near the centre of the lake an area of about an acre has a dirty, yellow, sulphurous appearance, and bubbles of gas emitting the offensive odour of sulphuretted hydrogen, and readily igniting on application of a light, can be seen rising from numerous conical mounds beneath a film of salt, sulphurous water. In this locality the pitch is quite soft and will scarcely sustain the weight of a man, though it is neither sticky nor dirty, and a piece can be extracted without soiling the hand, and kneaded into any shape by gentle pressure, a considerable quantity of water being squeezed out by the operation. This spot is supposed to be one of the main, if not the sole source of supply to the lake, and as careful surveys have shown this point to be slightly higher than the rest of the lake this view seems justified, although there is reason to believe that the lake is no longer being fed to any appreciable extent. A light portable railway traverses the edge of the lake, where the pitch is extracted in large blocks by pickaxes and thrown into trucks, and it is surprising to observe how easily the pitch is broken up into blocks in excavations about 2 ft. deep, and it is still more astonishing on returning to one of these pits a few days later to find the original level reached again, leaving practically no trace of a depression.

The pitch exhibits a cellular structure, being full of gas holes, which assume an oval shape. It contains 29 per cent. of emulsified water and about 25 per cent. of mineral matter, both of which can be largely removed by boiling; the water departing as steam and the sand settling to the base of the vessel. The whole contents of the lake are said by the manager to be in a constant but slow motion, thus frustrating all attempts to ascertain the depth of the pitch by means of bore holes as they became deflected. The management relates how a 2-in. pipe sunk in a trial hole 135 ft. deep disappeared, and reappears occasionally in far removed points of the lake to this day. The tube has become curved, and after showing itself for a short while it will disappear again only to protrude elsewhere at some subsequent date. This motion is also indicated by the appearance of trunks of trees with their roots complete, during the course of excavation. The author saw one of these unearthed, and as pitch was found beneath the

PLATE XXIII

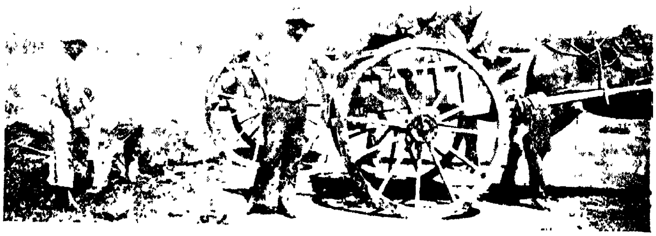

FIG. 22.—PITCH LAKE OF TRINIDAD.

Excavating pitch.

FIG. 23.—PORCELAINITE SHOWING LEAF IMPRESSION.

The rock is of a brick-red colour.

[To face page 188.

roots, to which much soil was attached, it was apparent that the whole had been carried bodily from the edges of the lake, and had risen upwards with the pitch that filled the excavation after temporary abandonment.

Clifford Richardson gives the composition of the pitch as follows the sand, consisting of fine siliceous particles with salts of minerals which have separated from the water, and some oxide of iron which transmits a red colour to the powder :—

Water and gas - - - -	29 per cent.
Organic matter - - - -	7 „
Mineral matter - - - -	25 „
Bitumen - - - - -	39 „
	100 per cent.

The ultimate composition of the bitumen is :—

Carbon - - - - -	82.33 per cent.
Hydrogen - - - - -	10.69 „
Sulphur - - - - -	6.16 „
Nitrogen - - - - -	0.81 „
	99.99 per cent.

At one side of the lake is a depression in the rough basin occupied by the pitch, and through this has been traced an overflow to the sea. The greater part of the distance is marked by numerous excavations, where pitch at some time or other has been extracted or is being extracted still. The width of this overflow probably does not exceed 100 yds., but as the land has been in the hands of numberless private owners, who, unless bought out by the Asphalt Company, worked the pitch themselves, or leased it to others, the stretch has been the scene of considerable activity.

This strip of pitch-bearing land was an object of prolonged litigation, and a generous source of revenue to Trinidad lawyers for many years. Pitch, being fluid in character, naturally swells into a pit soon after an excavation is depleted, the result being that the neighbours' lands are impoverished, and their ground level sinks or slips. Every proprietor, therefore, has a complaint against his neighbour, and work is usually suspended by an order of Court pending a judgment. A Government Commis-

sion, sent from England to settle the points of law and formulate laws, made certain recommendations which were eventually modified and approved.

The old idea that the lake was inexhaustible is as fallacious as it was absurd, for already the level of the pitch has fallen 7.1 ft., and as 100,000-150,000 tons are annually exported, and over 1,500,000 tons have been extracted, it is obvious that its life will not be endless. It is probable that great unexplored quantities underlie the sea off La Brea, and that one day the reclamation of this area will repay its cost.

Recent geological work in Trinidad has conclusively established the origin of the pitch lake. The asphalt originates from underlying petroleum-bearing strata, and the present pitch is nothing more than the accumulated unevaporated residue of millions of tons of petroleum which have exuded for ages from these oil sands. The only difficulty that presents itself at all is the manner in which a sufficient depression was formed at an altitude of 138 ft. above sea-level to contain that amount of pitch, an answer to which may be found in natural phenomena. The continued exudation of gas and oil naturally caused disintegration of the rock from which it issued, and as the angle at which the beds dip beneath the lake is supposed to be quite insignificant, the sands would occupy a considerable width, and much sand might be raised and be conveyed to the sea by the overflow. In course of time, after the formation of an extensive basin, a diminution of activity, due to partial exhaustion of the gas, or to the pressure of a great mass of solidified pitch, would lead to a reduced discharge, and consequently a less active disintegration of the rock, which in turn would result in a less contaminated quality of asphalt.

An example of such a naturally formed basin is to be seen in Trinidad to-day at Lagoon Boof, near Guayaguayare, where there is a great mud volcano about 100 yds. in diameter, in which gas and salt water issue from a pool of mud which overflows on one side into a stream. The mud will not support the weight of a man, and long poles pushed down fail to reach hard ground, even near the sides. A big basin of unknown depth has been formed on level ground at Lagoon Boof solely by the action of escaping gas

upon the formation through which it issues; indeed, such a lake under suitable circumstances would reproduce the pitch lake.

Reefs of asphalt in the sea off La Brea bear testimony to the magnitude of the overflow from the lake, and the removal of millions of tons of earthy matter is quite reasonable when it is conjectured what volumes were dealt with. The oil-bearing character of the sands of the La Brea district is proved by petroleum issues in the surrounding jungle, and more latterly by bore holes sunk in the vicinity of the lake. Reckoning the quantity of crude asphalt in sight and removed at 10,000,000 tons, this is equivalent to 3,900,000 tons of petroleum, allowing for no loss of volatile products.

The Bermudez asphalt deposits of Venezuela, situated in the swamps at the mouth of the Orinoco, have long been worked both by American and English companies, but in that country the material is not emulsified, but consists of exudations of thick plastic bitumen which readily softens under solar heat. The asphalt, which is derived from petroliferous strata, occurs amidst coarse grass in swampy ground, and issues from numerous cones spread over an area of about 1,000 acres. Its viscous quality renders its extraction exceedingly difficult, especially as the thickness of the deposit nowhere exceeds 9 ft., and it is often covered by several feet of earthy matter. In the rainy season, the area becomes so submerged that suspension of work is almost enforced, whilst in the dry season the coarse grass frequently becomes ignited, when the heat converts the upper portion of the asphalt into coke of no commercial worth. Mr Clifford Richardson gives the following information concerning Bermudez asphalt:—

ULTIMATE COMPOSITION OF BERMUDEZ ASPHALT.

Carbon	82.88 per cent.	Sulphur	5.87 per cent.
Hydrogen	10.79 „	Nitrogen	0.75 „

In its crude state it is mixed with 10-46 per cent. of water, but when dried it contains from 90-90.5 per cent. of bitumen soluble in carbon bisulphide, and 0.5-3.6 per cent. of mineral matter.

Recent drilling around the Trinidad pitch lake and in Venezuela has disclosed the fact that there are rich deposits of asphaltic oils whose viscosity and character closely agree with the asphaltic portion of the lakes mentioned. The pitch does not consequently represent, as was thought, the unevaporated portions of lighter oils that had accumulated in favoured localities, but the main bulk of certain specially heavy asphaltic bodies that impregnate the sands of those regions.

In Canada oxidised seepages of petroleum, which occur at intervals in the Ontario fields, are locally known as "gum patches," and discs of solid bitumen thrown up by the sea along the coast of Texas are known as "sea wax." These latter are sometimes 6-8 ft. long and 1-2 in. thick, having a concentric structure, which suggests their formation from submarine seepages of heavy petroleum.

In many oil localities shallow pits, sunk into the alluvium overlying the oil strata, or excavated in the productive seams themselves, will yield small supplies of heavy petroleum, which are often collected and utilised for the production of various grades of asphalt by further concentration. The extracted material is freed of water as much as possible by gravitation, and then heated in open pans until it reaches the desired consistency, after which it is run hot into barrels or tins and allowed to set.

Bituminous or Asphaltic Rocks.—In addition to the true oil-bearing strata, there are, widely distributed over the earth, arenaceous, calcareous, and argillaceous strata impregnated to a varying degree with bituminous or asphaltic matter. Some of the beds are permeated with a viscous semi-fluid substance, whilst others are only discoloured and exhibit no obvious indications of their bituminous character until chemically examined. Many asphaltic rocks or tar sands are merely outcrops of oil-bearing strata where the evaporation of the lighter products of petroleum has caused the concentration of the less volatile portions of the oil, or where the absence of the necessary geological conditions to produce and retain petroleum has led to the production of a dense intermediate product which saturates the bed and is retained in the pores

of the stratum. In many cases the whole bed is stained and darkened with a bituminous substance in a solid state, although the fissures and cleavage planes sometimes contain thin films of solid or semifluid bituminous matter.

Bituminous sands and limestones are usually impregnated with 8-12 per cent. of bitumen, and where the latter occurs in a semifluid form with a low melting point its extraction is occasionally undertaken on a commercial scale by boiling water, steam, or direct heating in cupolas. The bitumen can also be extracted in a pure state by treating the rock with solvents, and this procedure is sometimes followed when a high grade bitumen permeates the beds.

The mining and treatment of bituminous sandstones has been extensively conducted in the United States, and especially in California where bituminous rocks abound, but few such enterprises have been successful, owing to the large deposits of the crude native material which can be worked at a greatly reduced cost, and the cheap production of pure products from some low grade petroleum residuum.[1]

Bituminous clays and shales are very frequently found, in all parts of the globe, but usually, whilst they yield a considerable volume of gas when heated, the liquid product rather partakes of the nature of a crude tar than an oil, and they are rarely treated on a commercial scale.

The European asphaltic limestones largely quarried in France, Switzerland, and elsewhere for paving purposes, owe their usefulness to their purity, character of grain, and, to some extent, their regular impregnation with bitumen of suitable melting points and quality for withstanding extremes of temperature. Some of the asphaltic limestones in the United States contain as much as 25 per cent. of bitumen, but the irregular size of the grains diminishes their value for paving purposes.

The asphaltic sandstones, unlike the limestones, are almost

[1] For full details of such operations, see the excellent publication of the United States Geological Survey, "Asphalt and Bituminous Deposits of the United States," by Eldridge.

invariably sands in which the grains are cemented together by bitumen; and when the bitumen is removed by solvents the rock crumbles down to a sand. The amount and quality of bitumen impregnating asphaltic sandstones varies greatly, whilst the rocks themselves range between fine sands to grits. Most of the great asphaltic sandstone deposits have resulted from original impregnation with petroleum, which has mostly escaped, leaving only oxidised heavy residues impregnating and discolouring the strata.[1]

Bituminous, or tar sands as they are locally termed, cover vast areas in north-western Canada, where they often occupy a nearly horizontal position and in parts yield, under treatment, a petroleum of unusually light density. At some places liquid oil oozes from outcropping strata and wells sunk in their midst give small yields. In Spain, Portugal, Algeria, Madagascar and other places, there are frequent occurrences of similar rocks that have been examined with reference to oil. In Portugal the rocks of Torres Vedras often contain considerable quantities of liquid products which ooze forth under the influence of summer heat.

Burnt Bituminous Rocks.—Bituminous shales occasionally ignite spontaneously, and a slow combustion ensues for a long time, causing the shales to be burnt or vitrified and converted into brick. Messrs Wall and Sawkins, when they made their extensive geological investigation of Trinidad in 1860, reported the occurrence of a burnt *red* shale in many parts of the island which they nominated "*porcelainite*," as it was evidently a clay which had been subjected to considerable heat as a result of a slow combustion which had permeated the beds. Decomposition of sulphur compounds was probably responsible for the spontaneous ignition, after which combustion continued slowly through the bed, converting it into a red porcelain or brick of sufficient hardness to be utilised for road construction on an extensive scale. The heat has obliterated all carbonaceous matter, but throughout the burnt shales are to be observed

[1] Full information concerning the composition and employment of asphaltic rocks for road-making is given in Clifford Richardson's "The Modern Asphalt Pavement."

innumerable, well-preserved impressions of leaves of plants with details beautifully delineated (see Fig. 23, Plate XXIII.). Shales which have suffered such treatment are sufficiently hard to resist weathering and sea action much longer than the surrounding less durable rocks, and they have formed bold cliffs in several places round the south-western coasts of Trinidad.

A locality in Barbados known as Burnt Hill is evidently another example of the same action, slow combustion having converted a hill of bituminous shale into a hard brick-like rock, which has also been used for road construction.

Burnt shales have also been removed from wells in California at a considerable depth, thus showing that the process of combustion can spontaneously proceed without the assistance of air, even at great depths. Eldridge and Arnold thus describe the burnt shales of the Santa Clara district of California: "The siliceous shale and 'chalk rock' forming the crest of the mountains south of the Santa Clara have at many points been burnt to a bright red colour. The fuel that supported such fires was perhaps the originally contained petroleum. Opposed to this view, however, is the very considerable depth to which the shale has been altered to a brilliant red lava-like rock, hence it may be inferred that spontaneous combustion alone has brought about the modification." Burnt shales have also been reported in Athabasca.

A somewhat similar phenomenon is not unknown in England on the Yorkshire and Dorsetshire coasts, where Lias or Kimmeridge clays of a bituminous character yield a slight exudation of oil which occasionally ignites spontaneously, causing the surface of the cliffs to burn for a considerable time.

Native Bitumens.—Quite distinct from hardened oxidised surface seepages of petroleum, popularly known as pitch, asphalt, etc., which are always contaminated with earthy and organic substances, are certain high grade native bitumens of great purity, which are the product of actions other than atmospheric on petroleum during its passage along subterranean fissures in which they are now found. The high grade native bitumens always appear as intrusions, and fill fissures and fault lines in

strata overlying oil-bearing strata; and their occurrence in a district may generally be regarded as an indication of the existence of oil-bearing beds in the vicinity, although they may possibly be unimportant or at too great a depth beneath the surface to be worked or even tested.

There are numerous qualities of such bitumens found in many parts of the world, their character depending upon the composition of the petroleum from which they were derived, and also upon the nature and rapidity of the absorption or escape of the lighter products, which has probably been the main factor in their formation after the intrusion of the original fluid. The bituminous minerals vary from hard, brittle, glistening substances to softer dull masses, which even possess a certain fluidity and will gradually flow from fissures into an excavation. With the exception of ozokerite, which is an almost pure paraffin wax and varies in colour from nearly white to black, all the native bitumens are black and generally have a bright and even brilliant lustre. Their commercial worth depends upon their melting points, insulating properties, elasticity, and freedom from impurities, and according to these qualities the minerals vary in value from £2 to £30 ($9.60 to $144.00) a ton.

The common native bitumens mined in the United States, Barbados, Trinidad, Russia, New Brunswick, Syria, Nova Scotia, etc., have almost without exception a specific gravity exceeding unity, and they are known under a great variety of terms, such as Albertite (after Albert Mine, New Brunswick), Manjak, Grahamite (from Mr Graham, an operator), Impsonite (from Impson Valley, Indiana), Wurtzilite (after D. Wurtz), Gilsonite (after a Mr Gilson), Nigrite, Glance Pitch, and Elaterite.

One of the most common varieties is that to which Mr Clifford Richardson applies the exclusive term of Grahamite, and which he distinguishes as a pyro-bitumen in contradistinction to other minerals which exhibit different behaviour when treated with solvents. The main features which characterise Grahamites, and render their recognition possible in the field, are their brittle and dull nature, their frequent columnar structure, and the closeness of their melting points and temperatures of dissocia-

Fig. 24.—Native Bitumens.

1. Galician Ozokerite (mineral wax).
2. Russian Bitumen (high value).
3. Californian Petroleum Residue.
4. Barbados Manjak (high value).

Samples 2 and 4 show the conchoidal fracture characteristic of the higher grade bitumens.

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tion. The more valuable minerals, as Gilsonite and Manjak, melt and flow without decomposition at a moderate temperature, and when dissolved by solvents form products which, when applied to surfaces, are sufficiently elastic to prevent cracking under wide changes of temperature.

The veins of native bitumens have a width varying from an inch or less to several feet, and occasionally they open up into cavities many cubic feet in volume. The edges of the mineral vein often partake of a pencillated or columnar structure to a depth of several inches, and when the vein penetrates clays, the clays likewise to a depth of several inches are often characterised by a similar columnar form, evidently due to impregnation of material absorbed from the original bitumen-producing fluid. The veins often follow fault lines, whilst in other cases they penetrate fissures which deviate in several directions, rendering their development difficult. The original liquid character of native bitumens is proved by the occasional occurrence of pieces of unworn "country" embedded in the vein, as well as by the occasional penetration of liquid bitumen at points along the veins.

Much gas is evolved during the mining of native bitumens, and masses are often ejected with violence from the working face by gas which has collected under pressure in the mineral. Professor Cadman has also proved that native bitumens absorb oxygen from the air very readily, and as much care should be exercised in ventilating bitumen mines, and in adopting precautions against explosions, as in collieries.[1]

Solid native bitumens are distinguishable from coal, which some closely resemble in appearance, by becoming viscous or fluid on the application of heat, and by their solubility in solvents, such as carbon bisulphide, chloroform, petroleum spirit, etc. Most native bitumens are also soluble in crude petroleum or heavy natural oil, sometimes called Maltha. The superior quality bitumens mined in Syria, Barbados, and Utah never occur in wide veins, and it is the less valuable materials known

[1] See paper read before Institute of Mining Engineers' Annual Meeting, 1908, by Professor Cadman, "The Mineral Resources of Trinidad."

as Grahamites (Albertite and Wurtzilite) that are often discovered in veins many feet wide. On heating these latter they do not melt but intumesce, and the constituent hydrocarbons break up with the production of gas, a residue of carbon resulting if the heat is continued; but if heated with a proportion of heavy oil, in which they dissolve, disintegration is avoided, and a homogeneous product is produced.

The ultimate composition of native bitumens is not far removed from that of heavy petroleums, but naturally the component hydrocarbons are chiefly unsaturated, and consequently the bitumens are readily attacked by sulphuric acid. The following table gives the ultimate composition of a few native bitumens taken from Eldridge's "Asphalt and Bituminous Rock Deposits of the United States," and Clifford Richardson's "Modern Asphalt Pavement."

TABLE III.

COMPOSITION OF REPRESENTATIVE NATIVE BITUMENS.

Nature and Locality.	Carbon.	Hydrogen.	Nitrogen	Oxygen	Sulphur.
Wurtzilite, Utah	80.00	12.23	1.78	...	...
Gilsonite, Utah	88.30	9.96	0.32		...
Albertite, Nova Scotia	86.04	8.96	2.93	1.97	...
" " "	85.53	13.20	0.42	...	1.20
Grahamite, West Virginia	86.56	8.68	2.97		1.70
Egyptian glance pitch	80.87	10.42	0.19	...	...
Trinidad Lake bitumen	82.33	10.69	0.81	...	6.16

Ozokerite.—Ozokerite, which is one of the most valuable of the native bitumens, is chiefly worked in Galicia, where the mineral fills fissures in much-disturbed clays in the neighbourhood of the famous oil-bearing region of Boryslav. It evidently originates from a natural process of concentration, whereby certain liquid hydrocarbons of paraffin-bearing oils are abstracted, causing the accumulation of the residual solids in fissures, slip planes, and joint cracks of exceedingly disturbed strata into which petroleum had entered during subterranean disturbances. Ozokerite is found in small quantities in many districts besides

PLATE XXV.

FIG. 25 NATIVE BITUMENS.

1. Trinidad Grahamite, showing pencillated or columnar structure.
2. Bitumen formed on Surface from Exudations of Petroleum.
3. Egyptian Bitumen (very valuable).
4. Utah Wurtzilite.

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Galicia, but nowhere in such large quantities, although important unworked deposits exist on the island of Cheleken in the Caspian Sea.

Ozokerite has a specific gravity ranging from .850 to .950, whereas most other native bitumens have a density exceeding unity.

The ozokerite mines of Boryslav are now operated by modern hoisting machinery, and the mining is conducted by methods approved by the authorities. Ozokerite veins are found as yellow or dark yellowish-brown streaks or lenticles in dry compact clays. The clays show signs of considerable crushing, which has caused shiny slip planes to be prevalent. The wax follows these slip planes, and is especially concentrated beneath strata of rock, which clearly show the prevailing inclination of the strata as about 70°. Several working faces examined by the author, when he descended the mines in 1913, showed veins which did not exceed an inch to several inches in thickness. This material was yellow in colour, quite plastic, and could be kneaded into any shape by hand. The miners cast the purer wax into bags placed for its reception, whilst the surrounding clays are thrown into trucks and transported by a light tramway to the main shaft.

All the clay in the vicinity of ozokerite veins is impregnated with ozokerite, its extraction being effected by boiling the crushed material in water at the surface of the mine. The absorbed wax melts and floats on the surface of the water, from which it is periodically skimmed and run into moulds.

Very little water percolates into the mines, and there are fewer exudations of petroleum than would be anticipated within the confines of such a prolific oil-field. At a few points semi-solidified oils do issue from crevices and slip planes, proving the intimate association of the two minerals.

Petroleum gas of a distinctive odour is freely evolved at the working faces as the mining proceeds, but its percentage is kept to safe limits by artificial ventilation.

Crushed oak timbers, used as supports to the galleries, bear testimony to the crushing forces involved, and it is the need

for such elaborate and expensive timbering to support the workings that causes the extraction of ozokerite to be attended with so little profit when market prices fall.

In 1911 the author inspected the ozokerite mines of Starunia, Stanislau, Galicia, where very similar conditions were in evidence. A descent could only be made by a ladder in a small shaft, which had been thrown considerably out of vertical at several points. The descent was rendered more disagreeable by the constantly dripping water and oil which exuded at many points from the surface downwards.

As in Boryslav the wax occurred in numerous slip planes amidst highly inclined clays, showing every evidence of subjection to great strains. The clays in the vicinity of wax veins were impregnated with wax, which could be removed by boiling water.

Earth movements were evidently continually in progress, as massive oak supports were slowly crushed in all directions, necessitating constant repairs and attention to keep open the workings. Artificial ventilation was necessary to maintain an atmosphere which would support life, and stringent regulations were enforced to prevent an explosion of the inflammable mixture which must often be produced. Borings sunk in close proximity to the wax mines had yielded small productions of paraffin oils at increased depths, again demonstrating the close relationship of the two products.

Saline and Sulphurous Waters.—Few oil regions in the world are devoid of waters charged with salt and sulphur compounds, and they frequently contain traces of iodine and bromine, and some exhibit, it is claimed, distinct radio-active properties which, singly or collectively, attach to them a high medical value. Oil-field waters have not hitherto received the consideration they deserve, for their careful investigation and comparison might bring to light facts bearing on the origin of petroleum and its subterranean movements.

Most oil wells yield some water with the abstracted oil, and it is generally of a greater density than sea water, and contains a higher percentage of chlorides, and often of lime and magnesia. The high percentage of chlorides has been explained

in two ways—first, by the greater solubility of chlorides than sulphates, and consequently the deposition of the latter in concentrated solutions; and secondly, by the reduction of sulphates to metallic sulphides as described by Hoefer. Iron pyrites is very prevalent in oil-bearing strata. In contradistinction to the saline type of oil-field waters there is the alkaline class met with in the Wyoming or some other oil-fields of the western states of America.

Such waters are rarely suitable for condensing purposes or boiler use on account of the flint-like incrustations that form even when boilers are liberally blown off. Heavy flows of such waters may occur when drilling in oil-fields, the ejection being sometimes due to artesian effect, and sometimes to association with natural gas, that lightens the column sufficiently to raise it to the surface. The temperature may be normal or high, and in the latter case may be due either to chemical action or ascent from great depths.

This intimate and usual association of petroleum with salt naturally suggests the occurrence of the missing product where the other is present. It was the search for brine that led to the discovery of petroleum in the United States, and induced Drake, in 1859, to sink a well for petroleum. Operations which led to the discovery of oil at Spindle Top, Texas, and so disclosed the possibilities of the Gulf district, were being conducted for salt, and in Russia, China, and other countries, brine was the object of search and not petroleum, which latter subsequently monopolised all attention.

Rock salt is the central core of the numerous domes of Texas, Louisiana, and Mexico, from which such vast supplies of oil have been obtained, and in Roumania it constitutes the central body of some of the great oil-fields of that country; whilst the Saliferous (Miocene) series, a group always charged with salt, is inextricably associated with all the oil-fields. In the Ural-Caspian area of Russia massive rock salt occurs in the oil belt, and scarcely an oil district could be named where saline waters have not been recorded.

Issues of water from the edges of domes and outcropping

oil beds often cause salines, salt-licks, or salsas, where evaporation causes a deposit of salt at times in sufficient quantities to stimulate a local industry. The slow evaporation of such waters sometimes causes the salt to crystallise in clusters of rose-coloured crystals of great beauty.

Enormous flows of salt water have occasionally occurred in oil districts when drilling for oil. The famous well of Dos Bocas, Mexico, which in 1908 gave 400,000 tons (2,800,000 barrels) of oil in two months, eventually ejected only salt water at a temperature of 160° F., the flow being estimated at from 35,000,000-50,000,000 gals. daily. A characteristic sample of water from a Baku oil well gave the following results on analysis:—

ANALYSIS OF RUSSIAN (BAKU) WELL WATER.

	Grains per Gallon.
Total solids dried at 130° C.	3269.50
Chlorine (Cl)	1680.00
Nitric acid (NO)	0.90
Sulphuric acid (SO_4)	Trace
Carbonic acid (CO_2)	138.37
Iron (Fe)	0.91
Calcium (Ca)	5.88
Magnesium (Mg)	17.53
Sodium (Na)	1153.85
Aluminium (+little iron) (Al)	12.81
Sodium chloride (NaCl)	2768.45 = ¼ per cent.

The following analyses of three typical Burma oil-well waters are abstracted from a number published by Pascoe.[1] The results are given in grains per gallon.

Composition	Yenangyaung	Yenangyaung	Yenangyat
Suspended matter	50.73	136.25	52.60
Magnesia (MgO)	5.71	Trace	11.21
Lime (CaO)	8.21	6.74	8.11
Soda (Na_2O)	226.01	294.43	252.07
Potash (K_2O)	11.43	12.29	Trace
Chlorides as Cl	1.40	161.70	230.80
Carbonates as CO_2	76.10	106.30	25.47
Sulphates as SO_3	Nil	Nil	Nil
Ammonia, Free	0.99	0.91	0.59
Ammonia, Albuminoid	0.66	0.68	0.59
Oxidisable matter	7.10	10.50	7.05
Volatile organic matter	17.54	7.54	11.27

[1] "Oil Fields of Burma" Pascoe.

Waters charged with sulphuretted hydrogen are particularly common where inclined or disturbed oil strata outcrop, or approach the surface. Their issues can be readily detected by their injurious effect on vegetation with which they come in contact, and the peculiar slimy black or grey flocculent growth that clings to objects over which the water flows. Repulsive in odour and appearance, it is curious that these waters are often particularly soft and pleasant to wash or bathe in, and they are harmless for consumption, and very useful for boiler feed purposes.

Sulphurous waters abound in the Baku, Grozny, Berekei, and Kaikent districts of Russia. They occur in the oil-fields of Roumania, Galicia, Burma, East and West Indies, also Texas, Louisiana, and California; in fact, in nearly all oil regions of the globe. The hot springs of Grozny and Kaikent are much frequented by patients seeking relief from skin diseases and rheumatic ailments. It is interesting to note that the sulphur springs of Torres Vedras and Caldas da Rainha in Portugal issue from rocks of a bituminous character, in certain parts containing oil, whilst those of Salsamajore in Italy are derived from a petroliferous formation; indeed, both gas and oil are extracted from the water before it is led to the baths. Two natural sulphur springs in Trinidad near Guayaguayare and Point-à-Pierre are associated with oil rocks, and indicate a temperature of about 93° F. The daily flow of the latter spring is estimated at about 40,000 gals.

Flows of hot sulphurous waters have been struck at Grozny, Berekei, and on the island of Cheleken when drilling for oil; some of the waters at the latter place were so hot that drilling could not be continued. Two wells on plots 37 and 40, in the Grozny oil-field of Russia, yielded each 150,000 gals. of sulphurous water daily at a temperature of 104° and 117° F. respectively, and they were popularly frequented by the peasants for their ablutions.

Seepages of sulphurous waters frequently occur in fractured zones, and along lines of fault; indeed these latter are commonly traced in the absence of geological evidence by a line of seepages.

Areas approaching exhaustion in the Baku oil-fields were observed to yield increasing quantities of sulphuretted hydrogen, and more water vapour was noticeable with escaping gas.

The origin of sulphur in oil is not understood, as it appears to be connected with both primary and secondary oil. Iron pyrites is very common in oil-bearing formations, and its decomposition may have provided material for the production of other sulphur compounds soluble in or combining with the oil. On the other hand there is the suggestion that iron pyrites and sulphur are products of the reducing action of oil on sulphates. A by-product of the suggested reaction is carbon dioxide, which might, in the presence of water, cause first solution and subsequently re-deposition elsewhere of carbonate of lime.

During the great eruption at Erin, Trinidad, in 1911, great quantities of iron pyrites were expelled, and a well at San Christobal in Mexico repeatedly plugged with sulphur when heated to loosen the viscous oil that was thought to prevent the free inlet of oil. Some crude petroleums, as those of Texas, Mexico, Egypt, and Persia, and even the high grade dolomitic oils of Lima - Indiana, contain enough sulphur products to necessitate special treatment for its extraction.

Some of the oil-yielding limestones of Texas and Louisiana contained beds of crystallised sulphur, and in the search for oil great thicknesses of sulphur-impregnated limestones have been pierced. An important sulphur-producing industry has sprung up in the Calcasieu district of Louisiana, where an ingenious process has been devised to abstract and expel the sulphur impregnating the limestones. Wells are sunk into the sulphur-bearing limestone and superheated water is forced down between a 10-in. outer casing and a 6-in. inner one. The outer casing is perforated, allowing the water to pass into the rock, where it melts the sulphur, allowing it to sink to the base of the wells, from which it is raised through the 6-in. casing by compressed air. Single wells are said to have yielded as much as 400-500 tons of pure sulphur daily, and as much as 60,000 tons is said to have been raised from one well. Some of the limestones are reported to contain 70 per cent. of sulphur.

Oil Shales.—Under the general designation of oil shales are to be found, in many countries, carbonaceous or bituminous shales which yield, when subjected to heat, hydrocarbons closely resembling those constituting native petroleum. Oil shales do not contain oil or substances soluble in oil solvents, and are composed of fine argillaceous sediments through which is disseminated organic matter which often imparts to them a dark or even black tint and reduces their specific gravity. The petroleum is produced by the distillation of the shale, during which operation part of the embedded organic matter is volatilised and afterwards condensed, except such portion as forms a permanent gas, for subsequent distillation and refining, when the constituent hydrocarbons suffer further changes. Good oil shales contain from 20 - 30 per cent. of volatile matter and will yield, on careful distillation in modern stills with steam, from 20 - 50 gals. of oil per ton, leaving as a residue shaly matter in no way resembling coke although it retains some fixed carbon. The extensive and remunerative treatment of oil shales in competition with natural oils has only been made possible by the well-sustained high price of sulphate of ammonia, which latter is produced by using waste sulphuric acid from the oil refinery to combine with ammonia liberated from the shale during distillation. Some shales, such as the famous Torbanite mineral, first treated for oil in Scotland, and the kerosene shales of New South Wales, partake more of the nature of a coal, yielding 60-75 per cent. of volatile matter and 6-16 per cent. of fixed carbon. Such shales yield from 80-120 gals. of oil per ton.

The Scottish oil shales, so largely worked in the West and Midlothian district by some six large companies, are found in seams from ·1-8 ft. thick, lying in synclinal basins of the Carboniferous System (Calciferous Sandstone series), and they yield when subjected to distillation from 20-40 gals. of oil and the equivalent in ammonia water of 30-60 lbs. of sulphate of ammonia a ton. Shales which yield the most petroleum on distillation usually give the

least yield of ammonia water, and vice versa; but the nature of the product depends also upon the retort, and temperature of distillation, and the quantity of steam admitted to the retorts.

Where shales have come under the influence of intrusive volcanic rocks, which have been thrust into their midst in a heated state, a natural distillation has ensued, causing the shale to assume a "spent" or barren character, and the generated liquid and gaseous hydrocarbons have sometimes impregnated neighbouring beds and fissured ground. Under such circumstances considerable quantities of liquid petroleum and gas have sometimes accumulated both in the volcanic and sedimentary rocks, and been ejected with force when the vicinity was tapped by bore holes or mines. In some cases the fluid petroleum has been drawn into the pores of intrusive rocks as the heated mass cooled and caused the formation of a partial vacuum in the pores of the rock.[1]

The shales vary considerably in quality throughout their thickness, and a fair average value can only be secured by making a series of analyses from each few inches of depth and averaging the results.

In the Geological Survey's publication, "The Oil Shales of the Lothians," the character of the Scotch oil shales is thus described :—

"Oil-yielding shale, as known in the Lothians, is a fine black or brownish clay-shale with certain special features which enable it to be easily distinguished in the field. Among Scottish miners it is termed 'shale,' and the stratified rock described by geologists as 'carbonaceous shale' is distinguished as 'blaes,' from the bluish colour which it often assumes, especially when decomposed into clay. This distinction is a convenient one in several ways, and will be adopted in this Memoir.

"These two types are readily recognised in the field, but bituminous blaes may graduate into regular oil shale in such a way that it is impossible sometimes to draw the dividing

[1] See Sir Archibald Geikie's "Text Book on Geology"; also Memoirs of Geological Survey, "The Oil Shales of the Lothians."

PLATE XXVI.

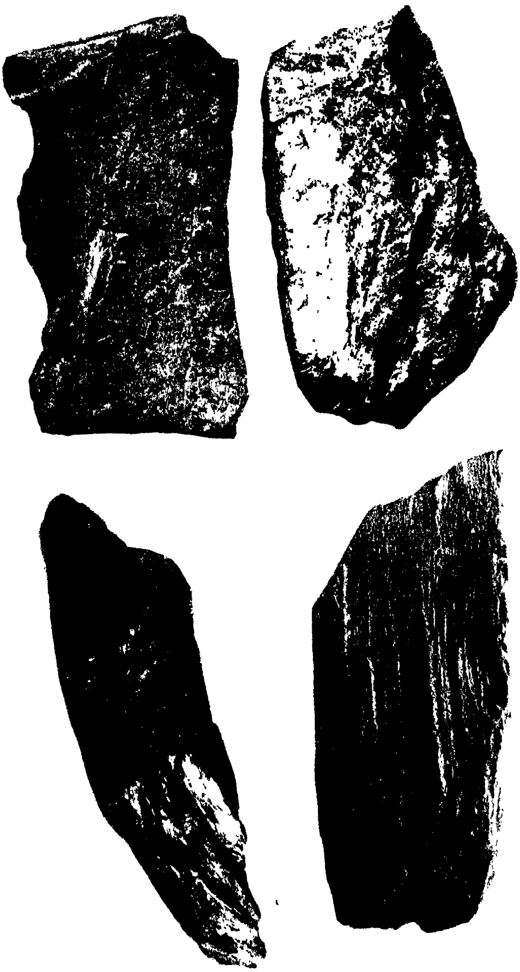

FIG. 26.—CHARACTERISTIC OIL SHALES.

1. Scotch Curly Shale.
2. Spanish Shale (Grenada).
3. New South Wales Shale.
4. Burma Shale (deep red colour).

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line between them. Bituminous blaes, if fairly rich in ammonia and volatile hydrocarbons, may pass for shale if a practical test proves it to be workable for oil and ammonia on a profitable scale. As a general rule, good oil shale can be distinguished by its brown streak, toughness, and resistance to disintegration by the weather. Ordinary black blaes is more or less brittle and often gritty, and when exposed to the air it cracks and crumbles into fragments which ultimately revert to their original condition of clay or mud. Oil shale, on the other hand, resembles hard, dark wood or dry leather, and its quality in the field is measured by the degree of facility with which it can be cut and curled up with the edge of a sharp knife. It is free from grittiness, and is often flexible as well as tough. Some seams, such as those that crop out on the shore at Society, near Hopetoun House, instead of breaking up like blaes, form slabs sometimes a couple of feet in length, and are washed about and the edges rounded by the waves.

"Miners draw a distinction between 'plain' and 'curly' shale, the former variety being flat and smooth, and the latter contorted or 'curled' and polished or glossy on the squeezed faces. The same seam may be partly plain and partly curly; and curly beds are often richer in oil than the plain portions. Shale is probably curly because it is rich, as the higher percentage of hydrocarbon in some beds may have rendered them more easily crumpled than the stronger but poorer bands alongside of them.

"In internal structure oil shale is minutely laminated, which is apparent in the 'spent shale' after distillation, when it is thrown out in fragments composed of extremely thin sheets, like the leaves of a book or flakes in a piece of pastry.

"In thickness the shale seams vary greatly. At certain localities they disappear and pass into ordinary carbonaceous blaes, and at others they swell to 6, 10, or perhaps 15 ft. in thickness, with subdivisions of barren blaes or ribs of hard calcareous or quartzose 'kingle.'"

Some oil shales from the province of Castellon, Spain,

examined by the author's firm, showed a considerable variation in the yield of oil at different levels in a bed only 4 ft. thick. Samples of shale showed 22 per cent. of volatile matter, of which 6-8 per cent. was water and 8-10 per cent. was non-condensible gas. A sample of the Castellon shale gave the following results on analysis:—

ANALYSIS OF SPANISH SHALE.

Crude oil		13.5 gals. per ton.
Ammonia, equal to 9.2 lbs. of sulphate of ammonia per ton.		
Spirit	sp. gr. .790	5.3 gals. per ton.
Lamp oil, first quality	„ .838	14.40 „ „
„ second quality	„ .864	14.90 „ „
Gas oil	„ .906	16.22 „ „
Cleaning oil	„ .918	2.60 „ „
Lubricating oil	„ .935	15.66 „ „
Scale		3.7 „ „
Total refined wax		4 per cent.

Oil from one of the Broxburn seams of shale gave the following commercial products on treatment in the refinery:—

Crude oil (setting point, 89° F.)	sp. gr.	.872	
Naphtha spirit	„	.740	1.36 per cent.
Burning oil	„	.810	31.60 „
Medium oil	„	.840	4.86 „
Lubricating oil	„	.865	10.30 „
„ „	„	.885	10.08 „
Solid paraffin (melting point, 115° F.)			10.52 „
Total products			68.72 per cent.
Loss in refining			31.28 „

Analyses of certain Asia Minor shales gave the following results:—

ANALYSES OF ASIA MINOR OIL SHALES.

Hygroscopic moisture, per cent.	5.65	6.55	4.95	3.95
Volatile matter, per cent.	15.50	21.80	23.75	17.25
Fixed carbon, per cent.	6.50	5.05	6.25	7.80
Ash, per cent.	72.35	66.60	65.06	71.00
Oil in gallons, per ton	30.24	41.66	41.88	30.25
Specific gravity oil at 60° F.	.910	.900	.876	.914
Nitrogen in terms of lbs. of Am_2SO_4 per ton of shale	3.00	7.12	7.60	7.12
Melting point of crude distillate	82° F.	81° F.	81° F.	85° F.
Distillate up to 200° C., per cent.	1.4	8.5	...	...
„ 200° C. to 250° C., „	15.2	9.5	...	...
„ 250° C. to 300° C., „	7.8	12.0	...	...
„ Above 300° C., „	63.5	59.0	...	...

Some New Brunswick shales gave the following average results on analysis :—

AVERAGE RESULTS OF ANALYSES OF NEW BRUNSWICK SHALES.

Hygroscopic moisture, per cent.	2.2
Volatile matter, per cent.	28.0
Nitrogen in terms of lbs. of Am_2SO_4 per ton	41.0
Specific gravity of oil	.890
Flash point	102.0° F.
Setting point	20.3 F.
Distillation up to 150° C., per cent	10.1
Specific gravity of distillate	.792
Distillate between 150 C. and 300° C., per cent.	40.4
Specific gravity of distillate	.845
Sulphur in crude, per cent.	2.20
Paraffin wax, per cent.	1.7

Interpretation of Surface Indications.—There has been a tendency in modern literature to disparage the value of surface indications and to indulge in needless platitudes concerning the construction that should be placed on phenomena admitting of simple interpretation and application. There is no mystery in the association of surface indications to oil-field structures and, notwithstanding all that has been inferred to the contrary, it is amidst the greatest surface manifestations that many of the most important oil-fields of the world are located. Until recent years, when detailed geological surveys of oil regions have been undertaken, and sequence of beds established by palæontological study, locations were largely determined by surface indications.

No more grave error can be committed by geologists than to draw sweeping deductions from data collected and applied with some success in limited areas. Many quite capable geologists have been misled into unqualified declarations, quickly falsified by events, and it is such unnecessary and reckless pronouncements that have brought geologists into disrepute in some fields amongst certain classes of operators. It must not be forgotten that there are lateral limits to lithological character and oil formation conditions, quite apart from structure, which might continue ideal if this claim were the determining factor.

Exudations of oil and gas, or accumulations of asphaltic

substances, corresponding to the line of crest of an anticline, however complex in sections, cannot but be regarded with interest. If all evidence of structure were concealed by overburden, such a strip of indications would amply justify prospecting. Carefully compiled logs of wells will gradually evolve the necessary data to form sections. Widening or narrowing of the indications suggest possibilities that can be applied in the fixing of well sites, and deflections in direction afford data for further conjecture. With little or no structural data it is sometimes possible to draw deductions, which, if intelligently applied, will reduce the chances of failure to a minimum.

Reference could be made to numerous cases where conclusive geological knowledge has led to failure, and wells have been relocated on purely surface evidence of oil with great success. In fact it is an error into which the author has himself fallen on several occasions, for there is always a temptation to locate sites in new fields at points where it is estimated certain sands will be reached at a calculated depth. Two factors have upset calculation. Either the dip of the beds has exceeded that estimated from surface exposures, or undisclosed strike faults have greatly modified the depths, and in some cases unknown mechanical difficulties have prevented the calculated depths being attained.

Prospectors in new fields should keep in view two points. In Tertiary oil-fields, oil is rarely confined to a single stratum or even several beds, and outcropping sands must not be considered to represent the vertical limits of an oil-bearing series; consequently, wells sunk amidst outcrops and exudations will generally strike deeper sources, often at inconsiderable depth. Modesty in depth should be encouraged in the location of prospecting wells in new fields, as drilling difficulties may be brought to light that necessitate considerable modifications in the plant to ensure great depths being attained.

In the absence of all geological structural evidence, converging or diverging lines of indications naturally support the view of pitching anticlines, and careful mapping of such outcrops often divulges invaluable data.

Anticlinal flexures, yielding little but regular indications of oil and gas at intervals in their course, occasionally present unusual local displays of surface indications that require some explanation. It is generally found that such points correspond with deflections in the course of the anticline, and that the area of their occurrence is much fractured and broken up. Such occurrences lead one to treat these areas with suspicion, and there is a disposition to give them a wide berth, but it is not unlikely that in some cases increased saturation has resulted from a combination of doming and fissuring. Uncertain or erratic results are to be anticipated at such points, but this does not preclude the likelihood of good or even exceptional results being obtained.

Visible indications of oil should never be definitely discarded, however unsuitable the apparent structure. The great Bibi-Eibat oil-field of Russia was first operated amidst seepages, and that initial area always proved the richest ; as this original area was receded from the productions were less. Grosny was opened up by a well sunk amidst surface indications, and the vicinity of the original well has always maintained its reputation as the richest in the entire field, corresponding, in fact, with the point of maximum elevation of the anticline. By far the most important oil-field of Burma originated amidst oil seepages, and the richest one coincides with the chief surface manifestations, and the highest point of the anticline. Development in California mainly followed petroleum seepages until geological investigations furnished the missing data. Most of the important Roumanian, and the famous Boryslaw field of Galicia were first decided upon entirely in consequence of surface indications, in some cases against geological advice.

Flattened crests or dome formations may bring to the surface considerable masses of almost horizontal oil sand presenting an extraordinary fine showing of seepages and asphalt deposits, which in no way detract from the value of the underlying beds, probably equally rich. Such a condition represents one of the rich areas in Trinidad that was quite neglected except by a few who appreciated its potentialities.

Exudations of oil bear direct and conclusive testimony to

the existence of petroleum, and experience will enable one to judge of the relative importance of such exposures, but with gas issues and brine springs and sulphur waters, an estimation of their value as an index to oil is less easy. An analysis of the gas gives some clue to its origin. If composed solely of methane or methane with carbon dioxide or nitrogen, its association with petroleum is less obvious than if it contains other hydrocarbons higher in the series, and condensible under pressure and reduced temperature. The above test is not conclusive, as some gases from oil sources are mainly methane, or the origin of the methane may be a source above an oil series, representing in reality either a migration product or the product of a source high up in the oil series, or, as it were, introductory to the oil source.

Even the occurrence of hydrocarbons other than methane is not conclusive evidence of the existence of petroleum, as in many oil regions there are defined and separated oil and gas belts or even horizons in the same sequence, yielding true oil gases only.

It should not be overlooked that oil seepages and asphalt deposits are evidence of loss of oil, and only constitute presumptive evidence of further supplies when the flow has not yet ceased or the source is still not exhausted. There are reasons for supposing that considerable quantities of oil have thus been lost in the past. Pebbles of hard ozokerite have been discovered in some of the more recent deposits of the island of Cheleken in the Caspian Sea, proving thereby that seepages had occurred for considerable periods; nevertheless, neither these prolonged losses nor the escape of enormous volumes of oil that combined to form the product contained in the Pitch Lake of Trinidad exhausted the neighbouring sands.

One may confidently assume that the undisturbed oil-facies of, say, the Appalachian oil-field, in spite of its geological antiquity, has retained a much greater proportion of its original oil contents than have the distorted Tertiary oil belts. The latter type of oil-field probably required much more favourable, and consequently much more rarely developed, structural con-

ditions for the preservation of commercial quantities of petroleum. A reason is thus furnished for the observed restricted extent, and yet on the other hand highly prolific character, of Tertiary oil-fields compared with those of Palæozoic or Mesozoic age.

Surface indications must be correctly interpreted before drawing deductions. Asphalt deposits are usually derived from seepages of oil, and it is often surprising what an imposing display is produced by an insignificant seepage of oil. Instances could be named of companies formed to exploit asphalt deposits that nowhere exceeded a few inches in thickness, and in the aggregate represented but small quantities. Superficial asphalt bodies usually constitute the oxidised residues of escaping films of oil that only indirectly communicate with the seat of their origin. Sometimes they arise from exudations of oil from outcropping oil sands, but much more frequently their extended occurrence is misleading to a novice. There are in some countries considerable thicknesses of sediments almost everywhere characterised by sweatings of petroleum, but nowhere yielding payable quantities of oil, in consequence of the absence of some essential lithological or other feature. The very prevalence of oil seepages will dictate caution to an experienced prospector until he has quite satisfied himself on the relative age and extent of the strata amidst which they occur.

Veins of native bitumen must be regarded with suspicion as indicators of payable oil. That they occur within the confines of oil-fields cannot be denied, but they much more frequently bear but a remote relationship to commercially productive oil sands. The Grahamite of Trinidad, the Albertite of New Brunswick, and the numerous other worked veins rarely directly communicate with oil-fields, although they are often in the region of such; but they do prove the occurrence of petroleum, and therefore must be regarded as a guide in its search. It is worthy of note that ozokerite fills fissures and impregnates clays overlying the main oil sources of Boryslaw, Galicia, and that at McKittrick, California, Grahamite veins may be observed in close proximity to productive oil wells. With a few exceptions only, the author is unaware of the

extensive occurrence of native bitumens within the confines of important oil-fields.

Oil seepages and their allied phenomena are attributable to the following causes :—

1. Outcrops of oil sands generally along denuded anticlines or monoclines.

2. Escape from unexposed oil sands beneath anticlinal crests through the medium of joint cracks or slip planes.

3. Strike, dip, or oblique faults, each detected by the relationship of the seepage to the general structure.

4. Igneous dykes or necks and saline domes.

5. Mud volcanoes, which are generally especially prevalent or important in dimensions where anticlinal flexures change their direction.

6. Unimportant but fairly regular impregnation of large masses of strata.

Even if the whole series of oil-impregnated beds is exposed on the surface, its study is useful in providing a clue to the identity of the beds in more favoured localities, where there might be no evidence of their character and extent to aid one in determining their value. Where there is no clue to the character of the source of the oil seepages, as in cases 2, 3, 4, and 5, their extent and nature must be examined, and experience alone will enable their importance as indicators of remunerative oil sources at workable depths to be determined. Prospectors experienced in Tertiary oil-fields will quickly assign a value to various phenomena.

Brine and sulphur water springs need not necessarily be associated with petroleum, but they are so frequent in oil regions that their occurrence should not be disregarded. They are especially prevalent in faulted regions, indeed their presence is often indicative of a line of fault in oil-bearing strata. Regions exhibiting these features should be carefully examined for gas and oil seepages, and if these latter are found, their association may be accepted as established.

Tar sands, so-called because the sands are impregnated with a heavy, viscous, semifluid mass, often softening during exposure

to the midday sun, are fairly widely distributed in Nature, and are occasionally quarried and treated for their bitumen contents or used for road dressing. Such tar sands in some regions represent the outcrops of true oil rocks that yield asphaltic oils at depth or where suitably inflected, but in other cases they are in no way associated with true oil-bearing strata. Outcrops of the rich oil-bearing sands in the region of the great oil-fields of the world are often darkly stained sands that betray no very obvious indications of petroleum. At other times they display the common phenomena associated with oil on a stupendous scale ; masses of asphalt, pools of oil, exudations of gas occurring for miles along the strike of the beds. Camping in a tropical jungle amidst such surroundings is a weird experience, the stillness of the night being broken by curious noises caused by gas forcing its way through resisting masses of asphaltic residues.

Caution should be exercised in estimating the commercial worth or productive value of oil deposits merely from surface indications. Neither the quality of the oil nor the quantity can be even approximately forecasted from such meagre data, and a whole series of unknown factors introduce so many elements of doubt in calculations that their value is obviously valueless, yet capable of many constructions. A repetition of conditions existing in proved oil-fields of commercial worth, and the certain occurrence of strata elsewhere of a known oil-bearing character, is often sufficient to recommend prospect drilling when the evidences of oil are nil, but the direction of maximum lateral variation and the possibility of unconformities should be kept in view.

Prospecting for Petroleum.—Whilst attention is usually first directed to likely oil territory by reports of oil seepages and allied phenomena, or more rarely by adventitious finds whilst drilling for water or other minerals, it is geological knowledge that in modern days eventually solves the problems involved in the prospecting of oil territory. Geological information must necessarily be vague in countries that have never been surveyed or geologically examined, and in many cases it is the drill that is relied upon to disclose data that might require years of study

over vast unpopulated areas for their accumulation otherwise. "*Wild-catting*" is a recognised and commendable practice when definite geological data are unobtainable owing to the occurrence of overburden, to the horizontality of beds over extensive areas, or to other causes. Oklahoma largely owes its great prosperity in oil to enterprising operators who have drilled test wells far away from proved territory with the sole encouragement that beds of an age elsewhere productive of oil would be penetrated within certain reasonable vertical limits. Often the oil sands were absent or barren, and the money employed in the work lost, but at other times oil-bearing sands of variable value have been struck. In some cases new sand bodies have been struck that were unknown to geologists, and non-existent in the original areas of development.

The development of most oil-fields provides the key to extended prospecting, and frequently results in the disclosure of unsuspected oil-bearing sand bodies. Careful levelling and the study of well logs will enable scientific operations to follow thickening sand bodies and evade thinning out or disappearing sands, and approach to the limits of irregular lenticles may be noted. Under the best geological advice risks must be run, as nothing but drilling will definitely establish the values of underground strata subject to so many variations that modify their value. The Moreni (Bana) oil-field of Roumania was developed against geological advice after some preliminary, unsuccessful shallow tests, and the important Chiciura district of the same country was proved by an operator who declined to accept tendered recommendations. Only recently the author, in his professional capacity, advised a trial well based on very meagre data, and almost in desperation, with the result that unknown sand bodies of considerable thickness and great productivity were struck, that opened up a wide area for highly remunerative development.

Oil prospectors thrown amidst masses of seepages and asphalt deposits or mud volcanoes are at least encouraged in their investigations by the knowledge that oil abounds in the vicinity, but where there are little direct evidences of oil, and the geology

of the region is a dead letter, early studies are often dispiriting, especially when large areas have to be covered where few, if any, outcrops occur.

Days and weeks might be spent in vain by a novice in seeking for indications of oil in some countries, where abundant supplies exist at depth. Outcropping sands impregnated with oil of medium density of the usual amber and light brown colour often exhibit no evidence of their oleaginous contents, and sometimes become bleached nearly white. Other sands have a natural brown colour, closely resembling an oil discoloration, but nevertheless yield no trace of oil on a cursory examination, nor emit the slightest odour. By digging some distance into the bed, their oil character becomes evident and the odour is pronounced.

Knowledge of a definite district enables an observer to discern quickly oil sands. They often assume some distinctive characteristic at their exposure which is at once recognisable, such as a certain tint, variegated appearance, efflorescences of certain salts drawn out by capillary attraction and deposited through evaporation of the water, or a special form of weathering.

Oil sands oozing petroleum can be at once recognised, often from a long distance, by their dark reddish-brown staining, but such discoloration must not be confused with water-bearing reddish-brown sands, to which they bear an extraordinary close resemblance at times. Heavy asphaltic oils produce a black stain which no weathering can remove, and often the outcrops are covered by a plaster of oxidised petroleum as asphalt, producing an effective antidote to weathering.

A curious phenomenon is reported by Mr G. E. Grimes in his geological report to the Indian Survey on the Yenangyang oil district of Burma, namely, that certain outcropping sandstone beds which show no signs of petroleum indicate a much higher temperature than the air and the surrounding strata, and these always prove to be oil-bearing at depth.

If the presence of petroleum is suspected in a sand displaying no visible evidence of impregnation, an excavation should be made, and the odour noted of a freshly broken fragment. Should this test fail to reveal evidence of oil a sample should be broken

under water, when, if oil be present, an iridescent film will often appear on the surface of the water. Finally, if still unconvinced, a crushed sample should be agitated with some solvent such as carbon bisulphide, chloroform, or even petroleum spirit. Unless fairly definite, such slight indications should be supported by other evidence and even deeper excavation, and an exposed surface not ordinarily indicating an oily appearance will sometimes show quite greasy spots under rain.

A note of warning should be sounded concerning prospecting in streams. Oil-bearing rocks on the banks or in the beds of streams often evolve oil which rises to the surface and floats away with the current. Oil disengaged and transported sometimes reattaches itself to certain other rocks and sands, giving them an appearance of true oil rocks. Detached fragments of oil rock are likewise carried long distances along streams during rains, and observed iridescence due to the disturbance of these masses may be mistaken for outcrops. Fragments of oil rocks in streams may often be traced up stream to their source, and much time may thus be saved in arduous exploration in dense forests.

Evolution of inflammable gas from decaying vegetable matter in streams is often erroneously associated with oil; and in the same way certain vegetable products of an oily-looking nature have been mistaken for oil. Films of oxide of iron have often led to long wasted journeys during explorations, although the most elementary test would have dispelled the deception.

The genuineness of oil seepages should be established beyond doubt if there is cause for the least suspicion. False evidence may be accidental or intentional, and in the latter case considerable ingenuity may be displayed in preparing an indication. The course of a leaky oil pipe line can be traced for years after its removal by a line of pronounced oil patches; and water wells, within the vicinity of oil storages, are a frequent source of local excitement in dry seasons when the level of the water falls sufficiently to allow a surface film of collected oil to reach the suction of the pump, and so be raised to the surface.

Natural seepages have often been brought to notice in tropical countries by the return of pigs or other domestic animals

of the region is a dead letter, early studies are often dispiriting, especially when large areas have to be covered where few, if any, outcrops occur.

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If the presence of petroleum is suspected in a sand displaying no visible evidence of impregnation, an excavation should be made, and the odour noted of a freshly broken fragment. Should this test fail to reveal evidence of oil a sample should be broken

Early prospecting of new oil-fields has often to be accomplished with little direct evidence of the structure. Theories are formed, and as quickly upset as work proceeds, but carefully compiled records of unsuccessful wells enable results to be correlated that give clues to future operations. Excellent results have rewarded drilling in Mexico, Egypt, and the Ural Province of Russia, where practically nothing was known of the structure, but failures in abundance are also to be recorded, as must be anticipated under such circumstances.

Test wells on eroded anticlines or monoclines not protected by overlap should be placed as far from the outcrop as reasonably deep drilling will admit, but on eroded anticlines, when deeper unexposed sands are suspected, a crestal location may be retained with advantage. Having once established the existence of a pool, drilling should be continued outwards both along the strike and dip at intervals not exceeding 500-1,000 ft., so that the cause of any change can be better ascertained. Leaps of considerable magnitude often land producers into difficulties by failing to provide adequate explanation for adverse results.

Districts affording inconclusive and conflicting dips, or presenting little surface evidence of structure, through excessive disintegration or thick overburden of alluvium, should be carefully contoured at close intervals. Structural details may thus be revealed that eventually lead to the solution of involved problems. Likewise, in the process of prospecting or development, careful well-head levels should be taken and underground contours drawn of any defined oil sand, rock stratum, water horizon, or other persistent and recognisable bed. Flattening or steepening dips will thus be traced, and the structure may be gradually evolved without recourse to doubtful surface exposures. In this connection Campbell M. Hunter has suggested that recognisable oil sands in wells should be referred to some fixed datum, and be marked by different colourings between certain limits of depth; thus lines of various colours would indicate strike lines and vividly disclose underground structures.

For note on "Divining" see Appendix.

CHAPTER V.

TYPICAL OIL-FIELD STRUCTURES.

Classification of Structures—Symmetrical Anticlines—Asymmetrical Anticlines—Diaper Structures—Monoclines—Saline Domes—Igneous Necks and Dykes—Relative Importance of Structure.

Classification of Structures.—Oil-field structures may for convenience be roughly classified into several general representative types that characterise commercially productive areas somewhat as follows:—

- Anticlines
  - Symmetrical
    - Simple folds—tending to form domes.
    - Folds with protruded cores (diaper structures).
    - Double monoclinal folds.
  - Asymmetrical
    - Simple folds—usually tending to domes.
    - Folds with protruded cores (diaper structures).
    - Overfolds.
    - Thrust faults.
- Monoclines
  - Simple inclination
    - Sealed by oxidation products.
    - ——— overlap.
  - Eroded anticlines
    - Sealed by asphalt.
    - ——— lateral variation.
    - ——— strike fault.
  - Terrace structure.
- Synclines
  - Normal.
  - Sagging anticline.
  - Ravine.
- Fractured rocks
  - Fault intersections, often with salt accumulations, sometimes with surface doming.
  - Igneous intrusions as dykes or necks.
  - Fissures or stockworks.

For comparison the classifications of Clapp and Hoefer are given:—

CLAPP.

I. Where anticlinal and synclinal structures exist—
   (*a*) Strong anticlines standing alone.
   (*b*) Well-defined alternating anticlines and synclines.
   (*c*) Monoclines with change in rate of dip.
   (*d*) Structural terraces.
   (*e*) Broad geo-anticlinal folds.

HOEFER.

I. Undisturbed country—
   1. Superficial, secondary accumulations.
   2. Regular and irregularly deposited lenses (Maikop).
   3. In sand bars, more or less regularly grouped (parallel) as at Pechelbronn—
      (*a*) At one horizon only (Zone).
      (*b*) Several Series).

Classifications—continued.

CLAPP.	HOEFER.
II. Quaquaversal structures— (*a*) Anticlinal-bulge type. (*b*) Saline-dome type. (*c*) Volcanic neck type. III. Along sealed faults. IV. Oil and gas sealed in asphaltic deposits. V. Contact of sedimentary and crystalline rocks. VI. In joint cracks of sedimentary rocks. VII. In crystalline rocks.	II. In disturbed country— 1. Normal anticlines (including geo-anticlines): symmetrical, asymmetrical, overfolded. 2. Diaper anticlines: symmetrical, asymmetrical, overfolded. 3. Domes: (*a*) independent; (*b*) on anticlines. 4. Sealed faults (Los Angeles). 5. Monoclines: (*a*) simple; (*b*) terrace structures. 6. Synclines and ravines (water free). 7. Fissures: (*a*) a single fault; (*b*) a faultseries (Hannover); (*c*) a stockwork (Klenczany, Florence).

In discussing the various classes of structure attention will be drawn to subsidiary features of interest that have often perplexed geologists till the tectonic details of the field were understood. A casual glance at many of the sections will suffice to demonstrate the futility of attempting an elucidation of the structure without the aid of the drill, and usually a profound knowledge of local palæontology. Surface indications alone, with only discouragement from geologists, have led to the prospecting and discovery of some of the great oil-fields illustrated.

Many of the oil-fields of the world are located along well-developed folds which follow defined general directions parallel with mountain ranges. These flexures change in form and character from point to point, at times flattening out and disappearing as other regions have taken up the strain in parallel directions. Persistent flexures displaying an immense variety of forms, and presenting numerous interesting features, are illustrated in the following pages. Variations of level and pitching of the folds alternately bring interesting geological series to the surface, or throw them to great depths, sometimes beyond the reach of present-day mechanical contrivances, thus breaking continuous belts into a succession of exploitable areas.

When studied in a more general manner, it becomes noticeable that many of the productive oil-fields of the world are located along

FIG. 26A.—TYPICAL OIL-FIELD VIEWS.

1. The famous "Columbia" well of the Moreni oil-field of Roumania. Photo taken when well was flowing.
2. The Campina oil-field, Roumania, showing River Prahova crossing the anticline.
3. View in Trinidad oil-fields where development has proceeded along a sharply inflected anticline.

[*To face page* 222.

the great geo-synclines which formed a prelude to the building of the mountain ranges now in existence. A particularly pertinent example of this is the Appalachian oil-field, the geo-syncline being still the predominant feature in the structure, the subsequent folding which has led to the accumulation of the oil in workable pools being tectonically very subsidiary. Another very important geo-syncline known to oil-field workers is that embracing the Borneo, Sumatra, and Java oil districts.

Before proceeding with the description of the tectonics of oil accumulation it is well to impress upon the mind of the student two very important points. The first is the extreme irregularity in shape of the sand bodies in such sedimentary facies as are usually associated with the occurrence of oil, and the second, more or less related to the first, the indirect connection between the superficial phenomena of petroleum and the source of such phenomena. Dealing with the first point, it is a matter to be deplored that in illustrating a book by means of diagrams showing typical oil-field structures, it is necessary to employ very much smaller scales than would enable minute stratigraphical divisions to be marked; and also regarding many fields there is a real lack of data concerning such matters. A diagram depicting a regular sequence of "oil sands" and clays represents conditions never met with in Nature. A given horizon may be marked by sands over a wide area but never as a continuous sheet. All sand beds, on account of the conditions of their deposition, are lenticular: oil sands are usually markedly lenticular with one dimension predominant. A sand body may therefore represent an elongated lens isolated among surrounding shales (probably many of the prolific Mid-Continental oil pools of the United States approximate to this type), or where the coarser sediment tends to predominate we may have one body connecting with another, both laterally and normally to the planes of sedimentation, so that it becomes quite impossible to construct a true map of the complex resultant body from the data supplied from the well logs. With the complications introduced when the strata are subjected to fracture and displacement of varying amount along fault planes, it is no wonder that curious ideas may prevail as to the relations of different wells in some fields; and also a little reflection will suggest

how, under favourable conditions, huge accumulations of oil may be tapped by one well.

When the superficial phenomena arising from oil accumulations in the earth's crust are studied, such as oil and gas seepages, mud volcanoes, sulphur springs, etc., it will be found that such phenomena are rarely traceable to a direct source. In the majority of cases they arise from faults. It is surprising how often seepages, apparently from sand, are found to be along the crest of an anticline, irrespective of any definite horizon, that is to say, are really from concealed beds, the actual rock yielding oil on the surface merely constituting a convenient exit. Bonarelli[1] has classified seepages as normal, longitudinal, and lateral. Normal seepages are crestal seepages as above described, longitudinal where pitching of an anticline causes an outcrop of an oil sand to occur across an anticline, and lateral where an eroded crest causes an oil sand to outcrop at its side, often an indicator of the oil prospects of a parallel non-eroded fold. To complete such a classification of seepages should be added others covering the various types associated with faulting, including cross-faulting (salt domes) and igneous dykes.

The prevalence of surface manifestations of oil is very variable. In undisturbed strata such as are found in the Appalachian field, mud volcanoes are unknown, and seepages are rare. In Mexico and along the Spanish Main, seepages on a tremendous scale are frequent, and of doubtful value as oil indicators. Elsewhere it is by no means uncommon for a petroliferous facies to give numerous seepages of high grade oil where no payable accumulations are ever found to exist. Thus the cautious prospector in a new region will refrain from placing too much reliance on such manifestations until he has tested their meaning with the drill.

Symmetrical Anticlines.—Terrestrial folds to which the term anticline is applied naturally partake of innumerable forms, and, according to the degree of flexure and the petrological character of the strata involved, vary considerably in the extent of faulting and subsidiary dislocation which, according to its magnitude, may or may not affect the petroleum contents. It is naturally along

[1] "La Formacion Petrolifera de Salta y Jujuy."

the crests that the oldest beds are exposed, and denudation may have proceeded sufficiently to expose along the crest and near flanks considerable outcrops of an oil-bearing series with its accompaniment of characteristic oil indications.

Sharp anticlines with highly inclined flanks, equal angular dips, and often faulted or eroded crests are common, and in some parts amidst mountains, such anticlines correspond with ravines that closely follow the anticlinal crest. Such flexures often expose moderate thicknesses of oil-bearing rocks and are invaluable for geological study, but they are rarely the seat of a thriving oil industry owing to their restricted dimensions, the ill effects of excessive faulting or erosion, and prolonged escape of hydrocarbon contents. Occasionally, however, where the grade of oil is high, or a local remunerative market exists, prosperous operations can be continued under such circumstances. In this connection students should be warned of the rarity with which anticlines correspond with topographical elevations; usually it is the reverse, for obvious physiographical reasons.

Rarely do anticlinal folds continue unbroken along level country for any considerable distance: nearly always the crest rises or plunges, causing certain interesting beds to approach, reach, or recede from the surface. Areas of maximum elevation may correspond with extensive exposures of oil-bearing strata, or they may represent points where the top of the oil beds only just outcrops, or they lie at considerable depth from the surface. It is these latter spots that are sought by petroleum geologists for especial study, as in the event of a good local development of oil sands and inconsiderable dips it is such localities that present the most obvious prospects.

Symmetrical anticlines with broad flat arches, and maximum development of the oil-bearing series of rocks which are mainly covered, are naturally rare in Nature, but when such conditions are closely approached oil-fields of great importance have been disclosed.

Fig. 27 illustrates the Yenangyaung oil-field of Burma, which has yielded about 5,000,000 tons (37,500,000 barrels) of high grade oil between 1888 and 1915. The oil-bearing Miocene (Pegu) beds just outcrop near the crest, where they lie nearly

horizontal, but become more inclined on the flanks where they are overlain by the Irrawaddy beds. Numerous small faults occur on the near flanks, and lenticularity is a feature of the oil sands. The prolific Singu oil-field of Burma is almost symmetrical at the point where the River Irrawaddy pierces the Yenangyat range, but the oil series here is struck much deeper.

Another classical example of an almost symmetrical anticline is the famous Bibi-Eibat oil-field of Baku, Russia. A wide flat arch of Miocene strata just reaches the surface, the beds dipping

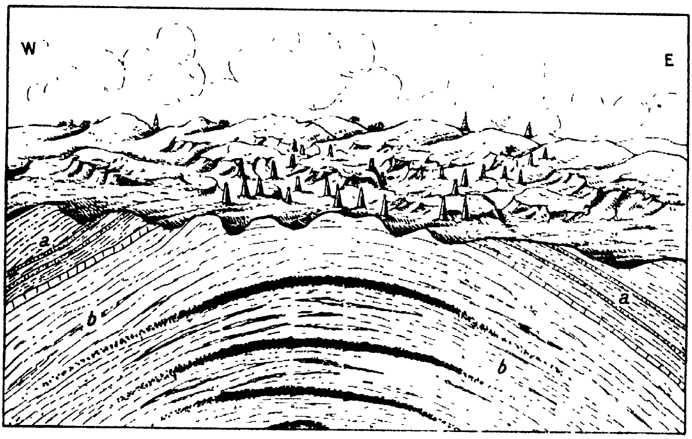

Fig. 27.—The Yenangyaung Oil-Field of Burma.
a, Irrawaddy. (Pliocene.) *b*, Pegu. (Miocene.)

way on the flanks, covered by the limestones of the Apsheron eries (Pliocene) that form imposing escarpments round the field. The oil-bearing series after plunging into a wide syncline emerge n the Yasmal valley to the south-west, where, exposed in a sharp nticline, they present unusual facilities for investigation, and lisplay oil-field phenomena on an almost unique scale. A uccession of oil-saturated sands may be traced over a considerable vidth, and almost every known type of oil indication may be tudied at leisure.

An almost symmetrical anticline characterises the Eastside il-field of Coalinga, California, where such excellent results

have been achieved by operating companies. Filipeshti de Padure in Roumania (Fig. 29) represents a fine example of

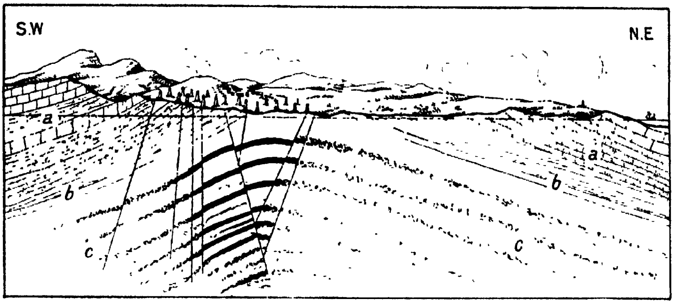

Fig. 28.—The Bibi-Eibat Oil-Field of Russia.
a, Apsheron. *b*, Meotic. *c*, Miocene.
(Pliocene.)

a symmetrical anticline. Surrounded by hills exhibiting features of structure in great detail, the ar a affords a particularly impressive

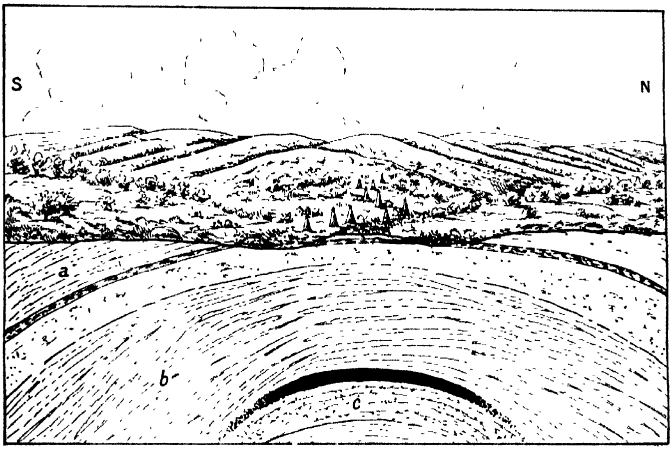

Fig. 29.—The Filipeshti Oil-Field of Roumania.
a, Dacian. *b*, Pontic. *c*, Meotic.
(Pliocene.)

vision. Beds of Pontic (Pliocene) age are exposed on the flanks and crest, and a paraffin-base oil is obtained from the Meotic

(Pliocene) formation at a depth of 3,000-3,500 ft. below the crest.

Two of the above cases, namely Bibi-Eibat and Yenangyaung, illustrate well the doming feature. In the former case the beds dip away from a central area of maximum elevation on three sides, whilst on the fourth the strata outcrop beneath the Caspian Sea. At Yenangyaung the anticline pitches gently both north and south of an elliptical area of maximum elevation, where drilling operations are mostly concentrated.

A variety of anticline, which deserves notice from the fact

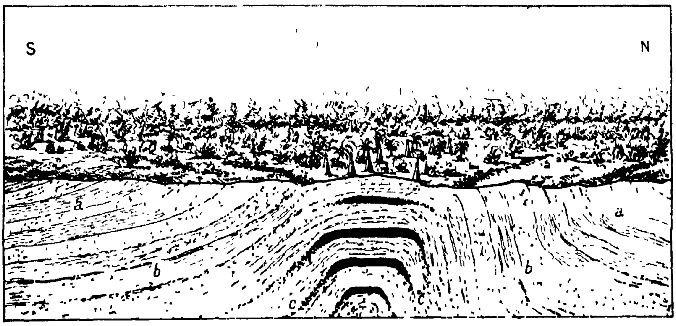

Fig. 30.—The Kampong Minjak Oil-Field of Sumatra.

a, Upper Palembang. *b*, Middle Palembang. (Pliocene.) *c*, Lower Palembang. (Miocene.)

that some prolific pools have been struck on such structures in Sumatra, may be regarded either as a flat-topped anticline (usually though not necessarily symmetrical) or as two opposing monoclines, using the word in its strict geological sense. In this type of anticline, which has been well described by Tobler,[1] the best results are obtained in the horizontally-lying central position; in other words, in a wedge-shaped block of ground the apex of which does not attain great depths and the productive sands becoming increasingly narrow with depth.

The strata in Kampong Minjak belong to the Palembang beds, of which the lower beds are Miocene, the middle and

[1] "Tijdschrift v. h. Koningl. Nederl. aardrijkskundig Genootschap," 1906.

upper Pliocene. Oil occurs mainly in the middle Palembang, three sands being important.

Asymmetrical Anticlines.—Anticlines with unequally dipping flanks present innumerable types of structure. The asymmetry may be small or it may be great, one limb frequently being nearly vertical or even inverted, whilst the other is gently inclined and very favourable for oil development. When unconsolidated plastic clays predominate, and there is a general absence of hard rock, exceedingly sharp flexures and overfolds may be formed without the oil

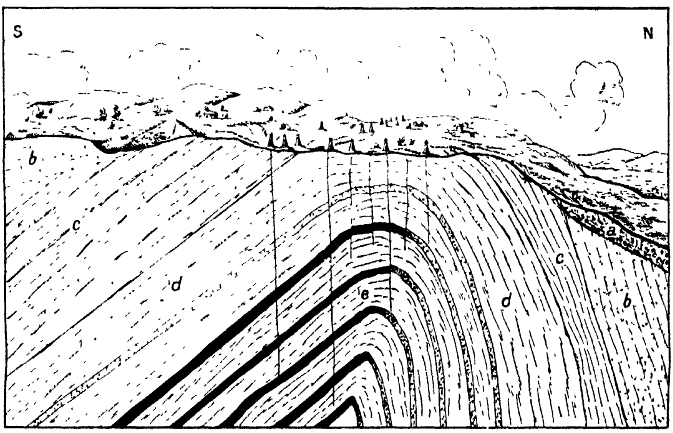

Fig. 31.—The Grosny Oil-Field of Russia.

a, Gravels. *b*, Meotic (Pliocene.) *c*, Middle Sarmatian. *d*, Lower Sarmatian. (Miocene.) *e*, Tchokrak. (Miocene.)

contents suffering escape, and a whole succession of creases, termed an anticlinorium, is sometimes produced, amidst which oil sands may be successfully operated. With a preponderance of yielding clays severely-contorted, enclosed oil-bearing sands will yield excellent productions of petroleum as fault planes are tightly sealed by the clays.

The structure of the majority of the oil-fields of the world is of the asymmetrical type. Russia affords a very typical example in the Grosny oil-field (Fig. 31), where oil-bearing beds of Sarmatian (Miocene) age form an uninterrupted belt for eight miles, along

which highly successful development has progressed. The point of maximum elevation is at Mamakai, where the higher oil sands reach the surface, and oil issues attracted operators to the district. The anticline pitches at an average angle of about 6°-15° both east and west. Operations to the north are checked by the verticality of the northern limb (40°-90°), but the 20°-30° dip on the southern flanks has permitted operations to be conducted for several miles without penetrating synclinal water.

Another example of an asymmetrical anticline is the Campina

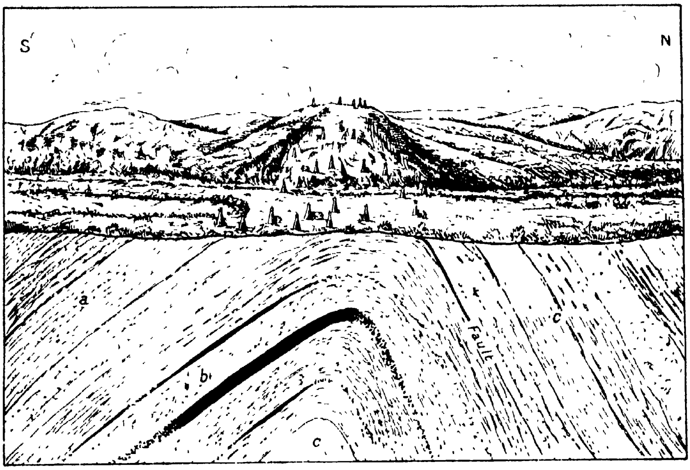

Fig. 32.—The Campina Oil-Field, Roumania.

$\underbrace{a\text{, Dacian.} \quad b\text{, Meotic.}}_{\text{(Pliocene.)}}$ c, Salifère. (Miocene.)

oil-field of Roumania (Fig. 32), where from strata of Meotic (Pliocene) age large productions of paraffin-base oil are abstracted. Burma yields typical examples of asymmetrical folding along the Yenangyat oil-field belt, stretching for some twenty-five miles in a northern direction. Here beds of Miocene age overlain by Pliocene yield oil of light density on the less inclined western limb.

Unusually sharp anticlinal folds and overfolds have been developed in Trinidad and Baicoi, Roumania, where lenticles of sand richly impregnated with light density oil have been exposed.

Overfolds often pass into overthrusts and remarkable structures of this kind have been recorded. Roumania yields excellent examples of this action. An interesting section is recorded by Ralph Arnold[1] in the McKittrick field of California, illustrated in Fig. 33.

Diaper Structures.—Although sharp folding, particularly where beds of variable strength are involved, is usually accompanied by more or less thinning out or even displacement in a direction parallel to the planes of bedding of the individual strata,

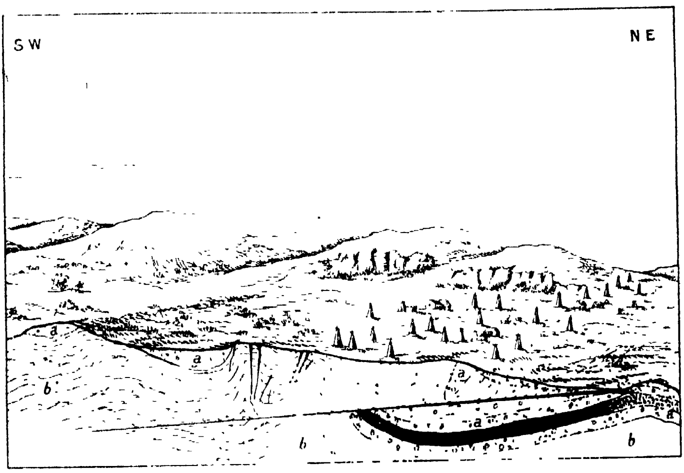

Fig. 33.—The McKittrick Oil-Field of California.
a, McKittrick. *b*, Monterey and Santa Margarita.
(Miocene.)

it is in the Carpathians, and especially on their southern slopes in Roumania, that this phenomenon appears in a very marked degree, so much so that Professor Mrazec has proposed the term "diaper structures" to express the results of this process. In these regions the underlying hard and tenacious lower Miocene rocks of the salt formation have been protruded through the newer and often more readily fractured upper Miocene and Pliocene beds, along lines of weakness, which probably began to develop before the latter were completely deposited. A hard nucleus of rock salt has often formed

[1] Bulletin 406, U.S. Geological Survey, 1910, p. 97.

the centre of this motion, and against the sides of the protruded rocks incline the sheared-off, tilted, and drawn-out edges of the various younger formations. Frequently the angle of dip of the newer beds bears only a remote relationship to that of the core beyond a very restricted distance. The Miocene masses usually hade considerably, producing overfolds that sometimes necessitate deep drilling through the Miocene to pierce beds of newer age that

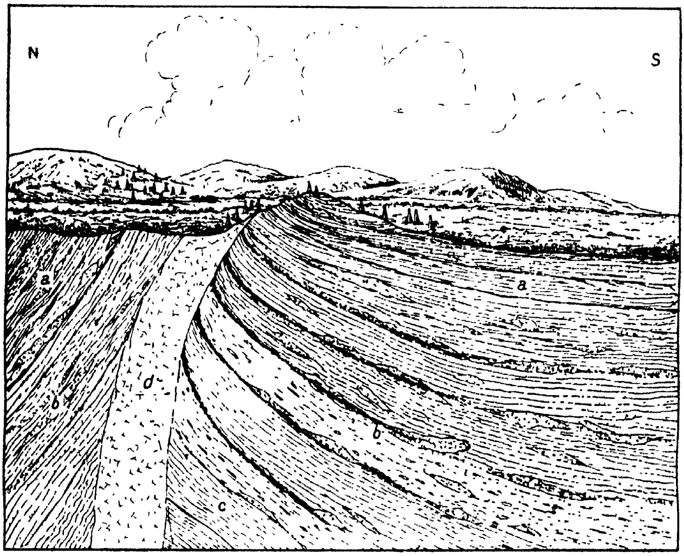

Fig. 34.—The Moreni (Stavropoleos) Oil-Field of Roumania.
a, Levantine. *b*, Dacian. *c*, Pontic. (Pliocene.) *d*, Salifère. (Miocene.)

come in contact with the overhanging core in depth. The disturbed region along the junction planes and the neighbouring sands have constituted receptacles for immense accumulations of oil eventually tapped by drilling.

Fig. 34 illustrates the famous Moreni oil-field of Roumania, where on the southern flanks of the Miocene core, wells of great productivity have been sunk to the Dacian; yields of 200,000 tons (1,500,000 barrels) per well being repeated many times. One well gave as much as 400,000 tons (3,000,000 barrels).

The Moreni oil-field is typical of the delay and loss resulting from failure to appreciate the true geological structure, in this case partly unavoidable, for it is seen at a glance that the details of the structure must remain hidden from mere surface inspection; they are only gradually understood as data come to light from well logs. Old hand-dug wells had yielded oil for many years, but only since 1904 has successful drilling been accomplished at Stavropoleos. This has been repeated at Gura Ocnitsa to the west, and subsequently at Bana (see Fig. 40) to the east along the same Miocene inlier. More recently, at Bana, the northern side of the structure has been developed, at first in the shallow syncline (Fig. 40), and then in the underlying Sarmatian rocks near the salt contact; and in 1915 this latter development was extended westward toward the older Moreni area, whilst about the same time an important westerly extension of Gura Ocnitsa was made at Ochiura. Thus it is that with the gradual elucidation of the true underground structure, the gaps in the proven oil-bearing Neogene aureole embracing the Miocene salt formation tend to disappear.

Fanlike forms are imparted to the beds in contact with the Miocene in the process of protrusion, introducing features of uncertainty that the drill alone can determine; fortunately, however, an abundance of fossils simplifies the identification of the strata being pierced.

In the Carpathians the older Cretaceous rocks have been pushed over the later Tertiaries from the Miocene upwards, along the outer margin of the mountains. In the south-eastern corner, where the principal Roumanian fields are located, *i.e.*, in the sub-Carpathians, however, the action is already much less accentuated than further back in the mountains, and in Figs. 29 and 32 are shown diagrammatic sections at points along the outer zone of folding, visible before reaching the plains of the Danube. These sections are at points where actual oil development has taken place, but the folding has not been sufficiently severe to admit of fracture of the Pliocene beds and the development of the "diaper" structure. A piercing of the Pliocene beds, not unlike those at Gura-Ocnitsa-Moreni, accompanies the oil pools developed at Baicoi-Tsintea, whilst between these two areas, at Filipeshti, the overlying Pliocene beds were merely folded into an anticline

(Fig. 29), nevertheless affording a structure favourable to the accumulation of oil in the Meotic (lower Pliocene) beds.

Six miles north of Filipeshti and Baicoi occurs the next zone of fracture, along which are the oil-fields of Campina, Telega, and Bushtenari. Lying nearer to the mountains the movements have been proportionately more severe, and the upper Pliocene rocks here disappear, whilst through the Miocene rocks large masses of Oligocene have been thrust.

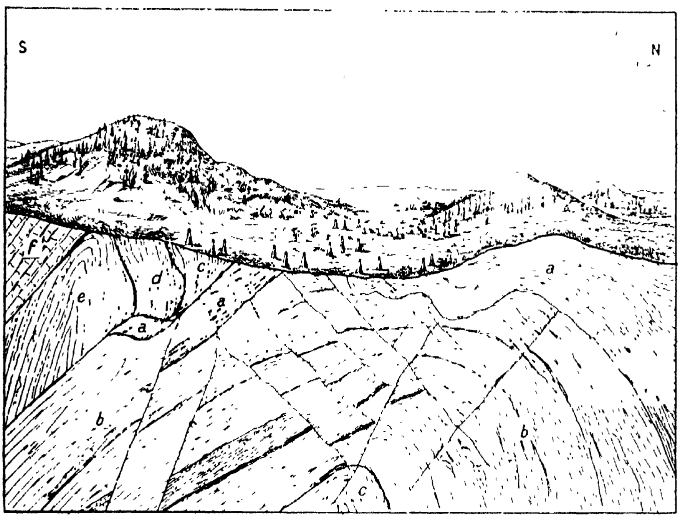

Fig. 35.—The Boryslaw-Tustanowice Oil-Field, Galicia.
a, Salifère. (Miocene.) *b*, Dobrotow. *c*, Menelite. (Oligocene.) *d*, Eocene. *e*, Hieroglyph Beds. (Eocene.) *f*, Cretaceous.

No structures like those last described have permitted commercially successful developments in Galicia, but nevertheless there is a distinct relationship between the fields. In Roumania oil is known in small quantities in the Flysch zone, but as we have seen, it is the later Tertiaries that yield the most abundant supplies.

In Galicia, the most important field, the Boryslaw-Tustanowice field (Fig. 35), has far exceeded all other localities in richness, yet excellent results on a smaller scale have been obtained from strata of Cretaceous, Eocene, Oligocene, and Miocene age elsewhere. The

same outward thrust from the mountains has forced the older rocks over the Miocene, the section of the Boryslaw-Tustanowice fold showing a central core of faulted Dobrotow beds (middle Oligocene) which, with the underlying Menelitic shales, form the source of the oil here worked, and it is overlain by the Miocene salt formation over which have been thrust, in ascending order to the south-west, Oligocene, Eocene, and Cretaceous rocks.

Monoclines.—The term monocline is here retained as it has passed into general oil-field phraseology as equivalent to a series of uniformly dipping beds, irrespective of the relationship they may have to the general structure of the district. Important oil-fields have been opened up where strata show a gentle inclination in one direction for considerable distances. Many of the American oil-fields are characterised by dips of such insignificance that for all practical purposes the strata might be considered horizontal, the cause of concentration consequently being imperfectly understood. Kansas-Oklahoma oil-fields are located within the flat continental area, on what is known as the Prairie Plains monocline, lying west of the Ozark dome, and it is doubtful whether the small differences of elevation there recorded would enable gravity to effect the accumulations of oil in the many pools located over hundreds of square miles. The structure in the important pools of Cushing and the Glenn pool are distinctly anticlinal, usually developing a group of domes.

As it is quite impossible to indicate intelligently in diagrams suitable for reproduction such gentle dips, this important class of structure has regretfully escaped illustration. The official publications of the United States Geological Survey should be consulted.

In Fig. 36 is shown a section of the Westside oil-field of Coalinga, California, the oil-bearing Miocene overlying unconformably the Eocene shales, and outcropping in the hills to the west of the belt after a lengthy monoclinal dip.

The Peruvian oil-fields are located upon monoclinal formations that extend inland from the coast. Dips do not generally exceed 20°-25°, but upthrow strike faults repeat the sequence at intervals, greatly extending the area of possible exploitation. The sands are

lenticular, displaying irregular impregnation, and speaking broadly the influence of faulting has not been very great. Secondary

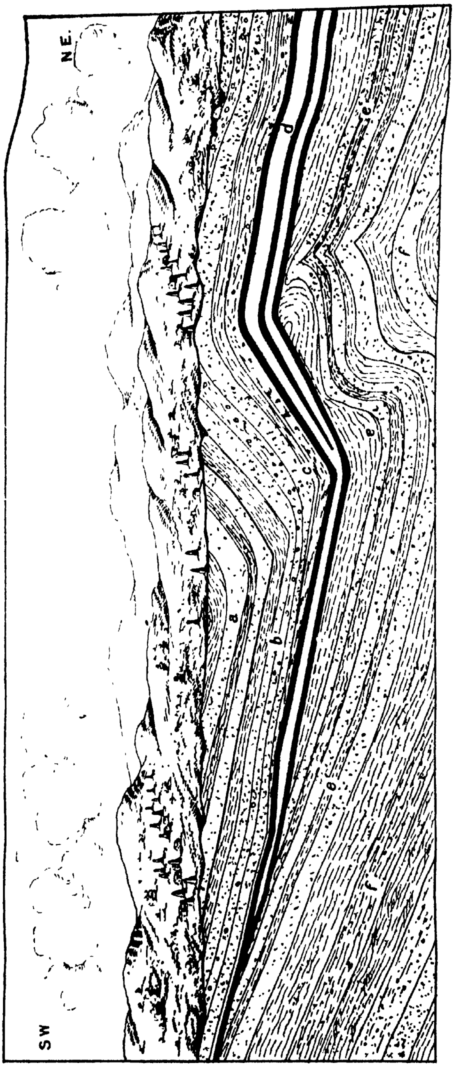

Fig. 36.—Coalinga Oil-Field, California.

a, Etchegoin. *b*, Jacalitos. (Upper Miocene.) *c*, S. Margarita. (Middle Miocene.) *d*, Vaqueros. (Lower Miocene.) *e*, Tejon. (Eocene.) *f*, Knoxville-Chico. (Cretaceous.)

faulting in a direction oblique to the strike has cut up and isolated large irregular blocks, amidst which are occasionally

struck areas of higher concentration as well as areas of low saturation.

Strike faults on monoclines would, under some circumstances,

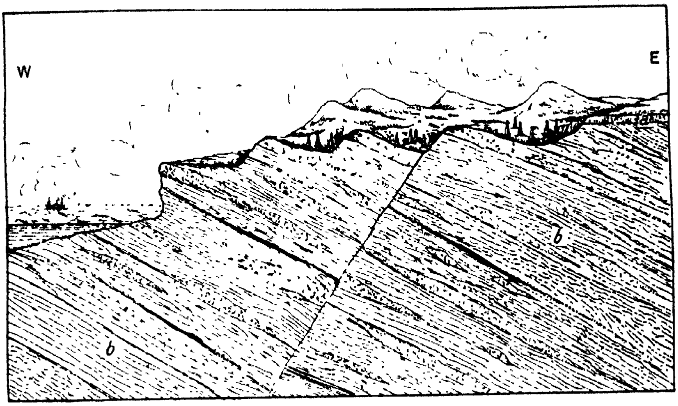

Fig. 37.—Typical Section in Peruvian Oil-Fields.
a, Late Tertiary. *b*, Eocene.

prove as effective for the accumulation of oil as true anticlines, many of which latter practically resolve themselves into faulted

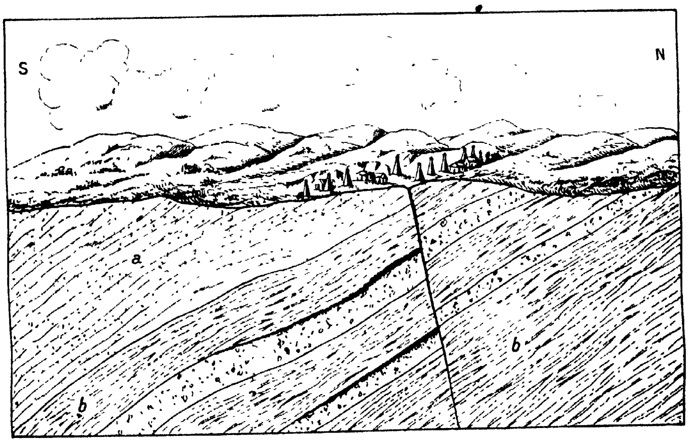

Fig. 38.—The Los Angeles Oil-Field, California.
a, Fernando Sandstone and Shales. (Pliocene.) *b*, Puente Shales. (Miocene.)

monoclines. Fig. 38 represents a section in the Los Angeles oil-field of California which well illustrates the beneficial effect of strike faulting, the sands on the lower side of the fault alone being productive.

Any slight crease, deformation, or change of dip in a gentle monocline may be the medium of concentration, and careful underground contouring from well logs will often divulge the origin of local saturation when not to be deduced from surface features: and more important still in many cases is the lateral variation of the rocks leading to the formation of sand lenses. Such areas of concentration were struck on the great monocline extending southward of the Bushtenari oil-field of Roumania, and in the Mid-Continental fields of America the influence of such deformations has been repeatedly demonstrated by underground contouring.

Another class of monoclinal structure might be termed the unconformable monocline. This is well illustrated by Fig. 39 showing the Shirvansky district of the Maikop oil-field of Russia. Concentration of oil has here proceeded in sands of upper Oligocene age, lying unconformably upon strata of Cretaceous age, and sealed by overlapping beds. Around islands of Cretaceous strata the sands proved productive, the initial yields of wells sometimes exceeding 500 tons (3,750 barrels) daily. The general facies of these Tertiary beds is marly to clayey, but where an old river course meanders through the Cretaceous islands, and its sandy beds have been well sealed by subsequent deposits, conditions are favourable for accumulation, as at Shirvansky.

Synclines.—Examples of prolific synclines are seen in Figs. 33, 36, and 40. In the Appalachian oil and gas fields synclinal oil is not unknown,[1] and in Roumania the extension of drilling on the low-dipping southern flanks of the Bushtenari and Moreni (Stavropoleos) field present something closely akin to synclinal oil.

At Moreni (Bana) a very rich small field of a true synclinal, though subsidiary, structure was operated with great success.

In this case the syncline must be regarded as quite a local phenomenon, and subsidiary to the main structure. Ordinarily

[1] See "Oil and Gas Fields of Green County," Stone and Clapp, 1907. See also "Steubenville, Burgettstown, and Claysville Quadrangles," Griswold and Munn, 1907.

synclinal accumulation is rare, and would naturally be confined to water-free rocks. The question of underground structure in regions

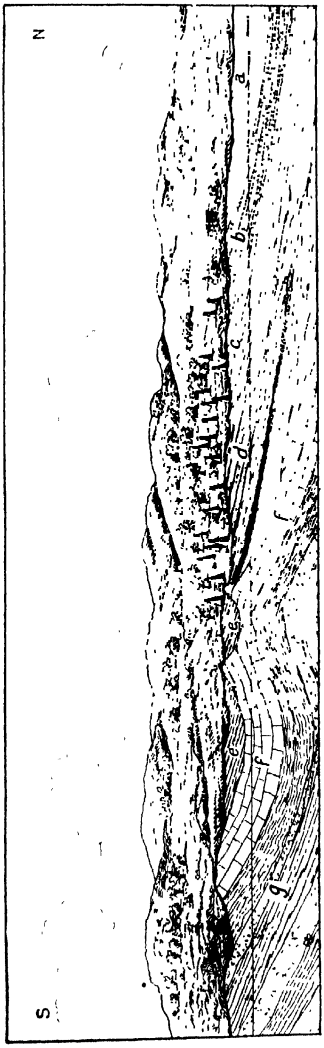

Fig. 39.—The Maikop (Shirvansky) Oil-Field, Russia.
a, Lower Sarmatian. *b*, Spirialis Beds. *c*, Tchokrak. *d*, Oil Formation. *e*, Foraminifera Beds.
(Miocene.) (Oligocene.)
f, Upper Cretaceous. *g*, Lower Cretaceous.

of relatively undisturbed rocks is peculiarly capable of study in the great Appalachian fields, where abundance of geological exposures

and excellent key horizons in the shape of coal seams sometimes outcropping, at others mined or penetrated by the drill, have been taken full advantage of b the American geologists, who have constructed maps showing "sub-soil contour lines" (oil-sand strike lines would be preferable), ften enabling depths of projected wells to be predicted with remarkable accuracy. Where an apparent lack of correspondence betw n the oil pool and the structure lines

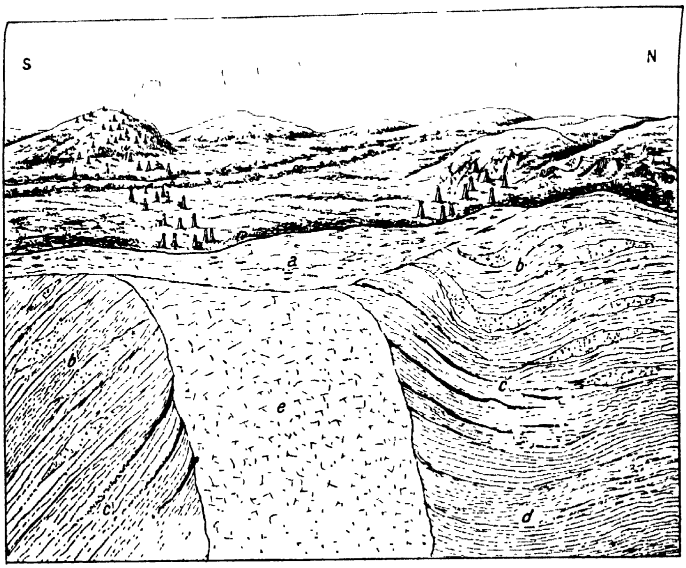

Fig. 40.—The Moreni (Banr) Oil-Field, Roumania.

a, Surface Deposits. *b*, Levantine. *c*, Dacian. *d*, Pontic.

e, Miocene Salifère. (Pliocene.)

N.B.—Beneath *d* on the N. paraffin-base oil has now been struck on the Meotic.

has sometimes been recorded, it has often proved traceable to non-coincidence of the form of the sand body with the strike. Although it is probable that sand bodies themselvés are much less irregular than is popularly supposed, there is no doubt that variations in size of grain, proportion of cement, etc., have the equivalence of lateral variation on degree of freedom of movement of the contained fluids.

It has been observed in the Appalachian fields[1] that the smallest,

[1] Griswold and Munn, United States Geological Survey, Bull. 318, Chapter I.

areas of complete saturation are found in the lowest, and therefore oldest sandstones. The area of saturation is less in each sand below the hundred-foot sand, and it is supposed that by some means the connate water has escaped, after perhaps aiding in the concentration of the oil in the first instance.

In proportion to the extent to which the water has disappeared, the oil has retreated down the slopes into the syncline, it being not improbable that this retirement of the level of water saturation has aided in the collection of scattered globules of oil. Roswell H. Johnson[1] has shown that when in motion the gravitational sorting of oil, gas, and water is readily accomplished where slight tendency to this would otherwise exist. The same author has shown[2] that gas bubbles tend to pick up a film or pellicle of oil, and in this way oil is transported in regions of low dip.

The descending pool of oil may reach the bottom of the syncline, or it may be arrested by a bar of closer-grained and finer-pored rock which would not hinder the water, or else fill up a hollow in the form of a ravine, subsidiary syncline, or even terrace. Griswold and Munn[3] call attention to the fact that in the Beaver quadrangle very small structural depressions seemed to hold accumulations of oil quite out of proportion to the area drained.

" In areas where the sand lies well above the water line, the oil occurs in very irregular pools, the shapes and dimensions of which are controlled by the porosity of the sand rather than by the direction of dip. The greater number of oil pools found at or near water line, lie in 'embayments' along the flanks of anticlines rather than on anticlinal 'noses' or promontory-like structures. This fact has an important bearing on prospecting, and is also of considerable interest as suggesting that the water line has in comparatively recent geologic time receded from a higher level."[3]

Saline Domes. — Some of the most extraordinary oil-field structures, whose origin is still in doubt, although the subject of considerable speculation, are the dome-shaped mounds of the

[1] "The Rôle and Fate of the Connate Water in Oil and Gas Sands," *Trans. Am. Inst. Min. Eng.*, 1915.

[2] "The Accumulation of Oil and Gas in Sandstone," *Science*, N.S., Vol. XXXV., No. 899, pp. 458, 459, 22nd March 1912.

[3] "Oil and Gas in the Cadiz Quadrangle, Ohio," United States Geological Survey, Bulletin 541.

Gulf field of North America. Along the low-lying coastal regions of Texas and Louisiana, where the strata over wide areas present exceptional regularity, with only gentle dips southwards, there are numbers of dome-shaped mounds rising abruptly from the plains to an increased elevation of from 10-50 ft. Around the domes, which do not usually exceed an area of a few hundred acres, there are often issues of salt or sulphurous waters, indicating some unusual local disturbance of the otherwise regular beds.

Attention was first directed to the mounds for salt, but the frequent association of gas and oil led to the drilling of a test well at Spindle Top, and a great outburst of oil was encountered, which immediately attracted considerable local interest to these structures. Prolonged investigation by C. W. Hayes and others of the United States Geological Survey, and by G. D. Harris and his staff on the Louisiana Geological Survey,[1] has practically established the fact that the core of all the Gulf mounds is rock salt, gypsum, and limestone, although in only a few cases has this been positively determined by drilling.

The partial elucidation of the structure of some of the mounds ndicates an area of local distortion, penetrating all the strata, even to those of Quaternary age, and conclusively assigning their origin to some vertically ascending body near their apices. The occurrence of sulphur and gaseous hydrocarbon emanations led to an early belief in the volcanic formation of the mounds, but so far there has been observed no evidence of intrusive rocks or metamorphic action.

An effort has been made to connect the mounds of Texas and Louisiana with certain fault lines running parallel to the chief faulting of that part of the country, and it has been ascertained that some of the domes are located at the intersection of these fault planes with others traversing a direction nearly at right angles. It is submitted that deep-seated hot waters supersaturated with saline matter have ascended along these points of weakness and deposited their dissolved salts when cooler beds were reached. To the force of crystallisation is ascribed the local upheaval of strata with the formation of the characteristic mounds.

[1] See "Rock Salt. Its origin, geological occurrence, and economic importance in the State of Louisiana," by G. D. Harris, assisted by C. I. Maury and L. Reinecke.

The oil and gas which have generally been found under high pressure in the strata above the salt, may either have originated from deep sources and risen with the ascending salt waters, or be the result of concentration to the apices of the domes from surrounding beds where oil was present in small quantities. The finding of oil deposits in the upturned edges of the sands penetrated by the salt mass, forming as it were an aureole around the salt, tends to strengthen the idea of an upward migration of the oil,

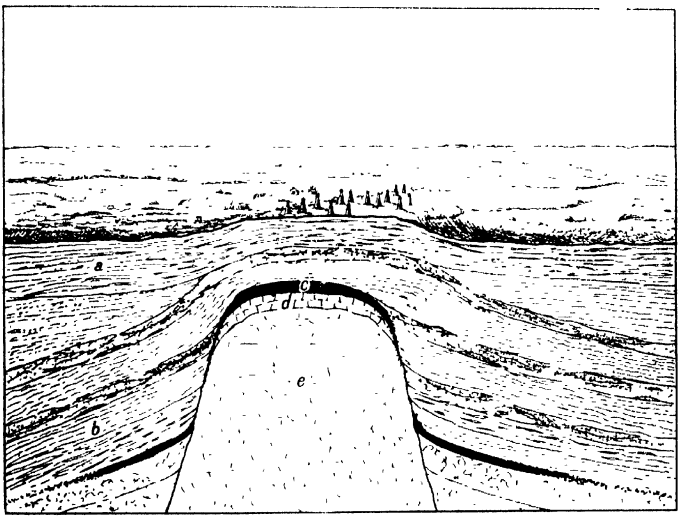

Fig. 41.—Hypothetical Section of Saline Dome.
a, Quaternary. *b*, Tertiary. *c*, Dolomite. *d*, Gypsum. *e*, Rock Salt.

and it is worthy of note that some of the deep drilling round Spindle Top, etc., has proved oil of a much higher grade than was met with at the apex.

Fig. 41 is a hypothetical section of a typical mound, and a structure of this type is supposed to characterise Spindle Top, Sour Lake, Saratoga, Batson, Dayton, Humble, Hoskin's Mound, Damon's Mound, Big Hill, etc., in Texas, and Hackbury, Sulphur, Vinton Welsh, Anse La Butte, Petit Anse, Cote Carline, Grand Cote, Belle Isle, etc., in Louisiana. The only other parts of the world where somewhat similar mounds have been reported are

Algeria and Mexico, but it is possible that the phenomenon may be responsible for some of the structures in Egypt, in the Hanoverian fields, and even in the Ural-Caspian area where perplexing aggregations of salt, gypsum, and limestone confuse geological study. In both of these latter fields the oil accumulation appears local and to be concentrated around fault intersections. It may be regarded as probable that if conditions of slow subsidence and deposition had occurred, as was the case in Texas-Louisiana, similar mounds would have been formed in the horizontal sediments.

It is said that in some mounds beds have been raised 1,000 ft., surface denudation proceeding contemporaneously with upheaval, and in some cases dissolution of salt has caused the centre of the dome to sink, leading to the formation of salt lakes or swamps. It is not improbable that some of the fantastic structures of the Roumanian and Galician oil-fields are associated with crystalline growths of salts that now form the cores of some of the oil-fields. Ascending hot, supersaturated waters might deposit their contents along the flanks of existing bosses, forcing neighbouring strata of a yielding nature laterally and vertically, thereby transmitting to them the fan-like structures which frequently prevail under such circumstances. In these cases it is not necessary to imagine an extensive migration of the salt, but rather a recrystallisation to adapt it to the new conditions under which it is placed.

The formation of domes has been the subject of an interesting paper by E. G. Norton,[1] who attributes their formation to ascending waters charged with mineral salts along lines of structural weakness first developed in palæozoic times. Incidentally, in criticising the theories of Veatch and others, he asserts that their conclusions seem "to impose upon Nature a criss-cross arrangement of fault lines of such regularity as to exceed her tolerance for geometrical design." The growth of travertine and calcareous sinter are supposed to have occurred contemporaneously with subsidence and deposition of littoral sediments, thus causing irregular masses due to alternate overlap of sediment or growth of sinter. The occurrence of gypsum is accounted for by the oxidation of hydrogen

[1] *Transactions of the American Institute of Mining Engineers*, February 1915.

sulphide, the sulphuric acid so formed converting the calcium carbonate of the rising waters into the relatively insoluble calcium sulphate. It is submitted that as sedimentation proceeded with the sinking of the area, the carbonated water attacked and redissolved the lower layers of calcium carbonate, producing open pores in which salt was deposited by the supercharged waters as a result of evaporation losses, release of pressure, etc. This theory does not account for the quaquaversal structures said to be imparted to the normally horizontal sediments of the district where some domes are developed.

Salt dome quaquaversal structures occur in the southern part of Vera Cruz, Mexico, where, however, much valuable geological data is frequently obscured by extensive marshes. It is stated by F. W. Moon[1] that the conditions resemble those of Texas with the exception of the superficial mound that there acts as an indicator. Oil is usually contained in a porous dolomite overlain by varying thicknesses of Tertiary (Miocene or Eocene) marls containing foraminifera, and fine sandstones either diatomaceous or infusorial, and underlain by gypsum, selenite, or anhydrite, which in turn cover the "farewell" rock salt. Rock salt was proved to a depth of 2,000 ft. in one field. Large areas give proof of much folding, and domes have been produced by cross flexuring. The main productive oil-field in the district was a dome or irregular quaquaversal with a subsidiary dome at the crest.

Igneous Necks and Dykes.—Mexico alone provides testimony of the beneficial influence of igneous intrusives on oil concentration. The association of volcanic dykes and bosses with seepages was long ago observed, but it was only deep drilling that disclosed the effect of the connection. Where, at a recent date, geologically speaking, intrusive dykes have pierced oil-bearing strata, as in parts of Vera Cruz, the distribution of petroleum has been modified, and may be almost independent of structural features in the sedimentary rocks. Areas are isolated by igneous dykes that arrest movements

[1] "Relationship of Structure and Petrology to the Occurrence of Petroleum," *Transactions Inst. M.M.*, 1910-11.

of oil in certain directions, where, unrestricted, the oil would gravitate or be transported by water.[1]

F. W. Moon has given the following interesting details concerning the association of the southern Mexican oil-fields with igneous intrusives.[2] In the northern part of the State of Vera Cruz, in addition to the frequency of igneous dykes, often no more than 2 ft. thick, there are numerous prominent and isolated volcanic necks which form conical hills rising abruptly some 400-500 ft. from the surrounding Tertiary marls, and these were

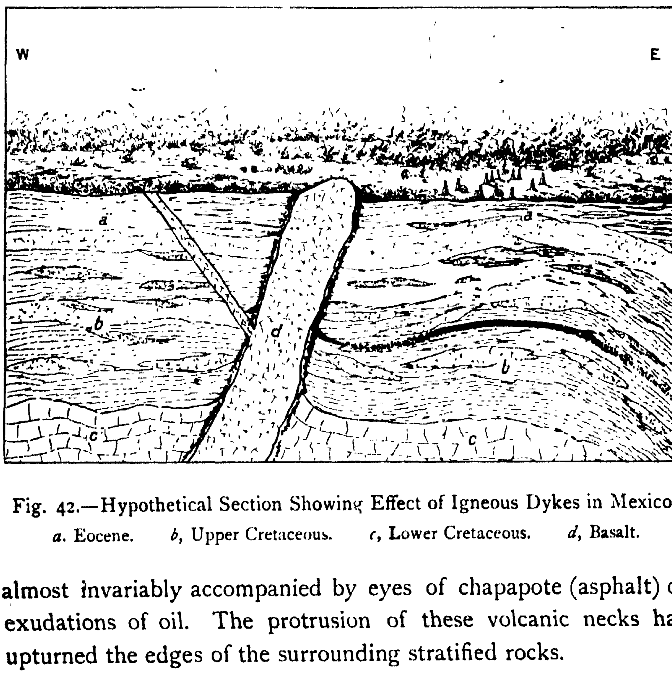

Fig. 42.—Hypothetical Section Showing Effect of Igneous Dykes in Mexico.
a. Eocene. *b*, Upper Cretaceous. *c*, Lower Cretaceous. *d*, Basalt.

almost invariably accompanied by eyes of chapapote (asphalt) or exudations of oil. The protrusion of these volcanic necks had upturned the edges of the surrounding stratified rocks.

El Pez, a hill in the famous Ebano oil-field, could be quoted as an instance of these conditions that produce a prolific oil-field. Many similar hills as Cerro Viejo, Cerro Chapapotal, Cerro Pelen, Cerro Toaco, Cerro Palmita, were igneous hills, some basaltic, others volcanic agglomerates, accompanied by escapes of petroleum,

[1] "The Mexican Oil-Fields," D. Day, *Petroleum Review*, June 5, 1909.
[2] *Loc. cit.*

PLATE XXVIII.

FIG. 43.—WHITTIER OIL-FIELD OF CALIFORNIA.

Showing wells sunk in almost vertical strata and general appearance of many Californian oil-fields.

[*To face page* 246.

but they have not generally yielded large supplies of oil when drilled upon.

The igneous dykes in northern Vera Cruz appear to radiate from or between basaltic centres, such as the Tantima hills and minor outstanding basaltic hills, and divide the country into more or less independent areas so far as oil is concerned.

Relative Importance of Structure.—Although at first sight the great variety of structures above described would suggest that structure itself plays a very minor rôle in the accumulation of oil, sight must not be lost of the fact that in most cases all the factors upon which the "anticlinal theory" is based hold good, even if the structure itself is so modified as to bear little resemblance to the text-book anticline. This theory, based on the obvious fact of the occurrence of oil along anticlines, affirms that, given a porous rock containing oil, gas, and water, folded between other strata which are non-porous to oil, these various fluids tend under the influence of gravity to separate according to their density, the gas along the crests of the anticlines, the oil below it, whilst the water remains in the deeper portions of the beds. The obvious difficulty of a gravitational sorting of oil and water, with probably less than 0.2 difference in density, against the high frictional resistances existing in sandstones, and often with very gentle dips prevailing, is usually explained by recourse to time. Be this as it may, most practical oilmen now believe that other factors play a not inconsiderable part in the movement of oil and gas, of which surface tension is one of the most important.

Looking now only at the question of structure, it must be assumed that by whatever means oil and gas tend to accumulate, their retention in any large quantity needs a cover to bar their continued upward movement. The most homogeneous igneous rock is not devoid of pore space, and all sedimentaries usually associated with oil series have from 15-20 per cent. pore space. Oil will traverse the finest sediments if they are dry, and we can therefore only suppose that the pore spaces of these finer sediments are occupied by water, and, owing to the superior surface tension of the latter, the oil is unable to displace it, however high pressure may be present; in other words, only a wet clay is impervious to oil.

The ideal structure would be a dome, including a thick bed of sand dipping gently to indefinite extent. In such a dome it is conceivable very high pressures might accumulate. It is not a form that is met with in Nature. Anticlines are usually very limited in a direction at right angles to their line of strike, more especially on the steep side, and although they often stretch for miles along the strike, it is rarely that they do so without break. In many cases they pitch one way, but at times both ways, thus forming an elongated dome, particularly noteworthy examples being Grosny and Yenangyaung. Where structures on a large scale do exist, it is not the rule to find the sands of the formation to extend equally far. This fact is often of vital importance to the preservation of the oil, and has been commented on by Carl D. Smith[1] with regard to the prolific oil-fields of northern Oklahoma, which are situated on the western flank of the Ozark uplift, and where the oil beds outcrop, but as the principal dimension of the sand bodies lies parallel to the strike, contained petroleum is as effectually sealed as in an anticline. Famous oil-fields like the Midway-Sunset of California display this same feature of discontinuous sands of great productivity far down the flanks of an outcropping monoclinal series, quite nullifying the preconceived class-book form of anticlinal concentration. The most prolific pools of Oklahoma, viz., the Glenn and Cushing, have, in addition, gentle anticlinal folding, subsidiary to the main monoclinal dip of the region.

Caution should be observed in drawing sweeping deductions from structures which fail to conform with conventional forms. Payable productions of oil may be obtained from steeply inclined sands, as in the case of the Whittier oil-field (Fig. 43) of California, and certain Russian and Roumanian fields.

Subsidiary structures of purely local significance should only be considered in relation to the general structure when deciding upon the merits of an area. Points which have yielded to pressure in soft Tertiary strata often become crushed zones which partake of the nature of an anticlinorium. Such zones of sharp flexuring and distortion are particularly noticeable in the nearly horizontal Tertiary of parts of Trinidad.

[1] Bulletin United States Geological Survey, "The Glenn Oil and Gas Pool and Oklahoma," p. 27.

CHAPTER VI.

ORIGIN, COMPOSITION, CHARACTERISTICS, AND TREATMENT OF PETROLEUM.

Origin of Petroleum and Natural Gas—Theories of Oil Formation from Organic Matter—Relationship of Paraffin and Asphaltic Oils—Relationship of Grade of Oil to Depth—Composition and Characteristics of Petroleum and Natural Gas—Uses of Petroleum Products—Distillation of Petroleum—Refining.

Origin of Petroleum and Natural Gas.—The problem of the origin of petroleum has been the subject of scientific controversy for many years, and numerous chemists and geologists of distinction have been led into an expression of opinion at some time or other. The problem is, however, still awaiting a theoretical solution that will give general satisfaction, although the more active development of oil-fields and an increased scientific interest in petroleum has led to a much clearer perception of the necessary antecedent phenomena resulting in the natural formation of liquid hydrocarbons. World-wide exploration has proved petroleum to be no curious fluid, produced, as was formerly thought, in a few isolated spots on the earth where peculiar conditions existed, but a common, widely-distributed product of Nature, which has been disseminated amidst sedimentary rocks of various kinds and ages.

In seeking the origin of petroleum, therefore, one must not introduce extraordinary theories for its production in certain localities, but must consider only such views as will account for its extensive production and wide distribution by common processes of Nature. In certain exceptional cases bituminous compounds which are closely allied to petroleum, may call for some unusual explanation, such as the occurrence of bitumen in meteoritic stones which have reached the earth, and the existence of similar products in volcanic rocks, but these isolated examples bear no intimate relationship to the enormous accumulations of

petroleum which it is the aim of the oil prospector to locate and develop.

Modern discoveries have enabled the chemist to produce synthetically many of the constituents of petroleum by reactions in the laboratory, and even to reproduce some of the isomeric forms of the hydrocarbons which occur in crude petroleum. Many of the theories advocated or supported by leading chemists have been proved to be quite untenable, although no doubt ever existed that oil could be produced in the manner described, but geological considerations prevented the acceptance of these as natural methods of oil formation.

There are two general theories commonly presented to account for the origin of petroleum, which may be described as the Inorganic and the Organic respectively, of which latter both animal and vegetable sources of origin find distinguished advocates.

Inorganic Theories of Origin.—The inorganic theories attribute the origin of petroleum to chemical reactions in the interior of the earth, mostly involving the formation of gaseous hydrocarbons which rose in fissures from great depths and condensed and accumulated in upper cooler strata of a porous nature. This idea found many influential advocates at one time, and the ascertained action of water on the carbides of certain metals which results in the liberation of hydrocarbons was considered evidence in support. Some of these theories involved intricate chemical reactions and peculiar terrestrial conditions of temperature and pressure that made them extremely improbable, but they have never been generally accepted, chiefly because much more simple and probable reactions will account for the occurrence of petroleum, without introducing the many difficulties these theories make it necessary to concede.

In nearly all oil-fields petroleum is confined to strata within definite vertical limits. Above or below an area of enrichment lie unproductive sedimentary strata, often quite suitable for the storage of petroleum. Had the hydrocarbons emanated from great depths it is difficult to understand why the lower beds were not impregnated, or why no evidence remains of the

exuding fluids in the crevices and fissures themselves. In nearly all cases where there are veins of bituminous material disseminated throughout strata, it is usual to find sedimentary beds impregnated with asphaltic matter beneath or in the vicinity of the impregnations, thus disclosing their origin.

The occasional occurrence of bitumen in vesicular volcanic rocks, where they are not in contact with petroliferous formations, may be due to the condensation of emanations of hydrocarbons (possibly derived from contemporary distillations of organic shales) at the time of the disturbances resulting in their upheaval, but in no case do such rocks yield more than a trace of petroleum. Igneous rocks are obviously unsuitable reservoirs for fluids were petroleum produced beneath and amidst them, and it appears more than a coincidence that so many of the world's most important oil-fields are developed in strata of a recent (Tertiary) geological age, which are generally underlain by an enormous thickness of older, unpetroliferous, sedimentary strata which would have arrested the upward movement of any deeper-seated products.

Theories involving intricate chemical reactions based only upon hypothetical considerations have found no acceptance with persons intimately acquainted with oil-field phenomena, although some of the suggested inorganic reactions are extremely ingenious, and show what persistent efforts to produce oil have followed a conviction that it has been derived from mineral matter.

Eugene Coste is the staunchest remaining advocate of an inorganic origin for petroleum, but his writings partake more of the nature of a general criticism of the acknowledged weak features of theories of organic origin than a presentation of convincing argument in favour of his own case. It is impossible to deny that petroleum, in anything but traces, is in no way associated with volcanic or even metamorphic rocks, nor is true vulcanism anywhere recorded within effective distances of oil-fields. Mendeleieff and other scientists were under the erroneous impression that mud vulcanoes were related to true volcanic phenomena mainly in consequence of the occurrence of oil-fields near mountain ranges.

One point of criticism levelled against the organic theory by advocates of an inorganic origin is the difficulty of accounting for sufficient organic material to produce the immense supplies of petroleum found in certain localities. It is claimed that the matrix of the earth provides inexhaustible quantities of emanations; but two points are perhaps overlooked, or at least conveniently disregarded, in this connection. Firstly, migration, equally applicable to both theories of formation, causes concentration in suitable localities, and accumulation may represent the product of a wide area; secondly, geology affords innumerable examples of deposits of both animal and vegetable life in quantities capable of accounting for such supplies if a mere fractional percentage of their volume is considered to be convertible into liquid and gaseous hydrocarbons.

Organic Origin of Petroleum.—The organic origin of petroleum now commands almost universal acceptance, although there is no general agreement either as to whether oil is derived from vegetable or animal matter, or as to the forms of life that provided for its genesis. Some are bold enough to deduce from very inconclusive data conclusions of one kind or another that never satisfy the most obvious critical queries, and only provide plausible explanations for certain carefully selected cases that are rarely reproduced. Closely associated with the problem is the question of whether the oil has an adventitious or indigenous origin.

Methodical mapping and detailed geological study by Government geologists who are empowered to demand information from producers, and authorised to publish their detailed and matured conclusions, has gone far to remove much of the mystery surrounding the problem. Circulated data from reliable sources have aided and fostered observations in many centres where before local scientists had to rely upon their own energies, with nothing concerning other areas for comparison.

Roumanian geologists, under the able guidance of Professor Mrazec of the Bukarest Geological Institute, have clearly demonstrated a definite relationship between the salt facies of the Miocene Saliferous series of the Carpathians and the oil-producing strata of Roumania. Especial interest attaches to this work, as it

does not relate to a single or several oil-fields in a cramped region, but applies to a number of oil-fields, spread over a wide area on the flanks of the Carpathian Mountains, which range sweeps round in a curve presenting changing strikes and innumerable phases of structure.

Unlike many oil-fields, the Tertiaries of Roumania and their continuation on into Galicia are particularly rich in fossils, and unusually good palæontological data are available for the recognition of geological horizons. Many fossils naturally persist through a considerable vertical range of strata, but there are certain species restricted in their range and development. So sound a basis for study could not fail to throw light on problems elsewhere very obscure.

The Salifère is characterised by prevalence of salt, and its local development often consists of massive rock salt, which has thrust its way upwards through softer, newer beds on many of the anticlinal folds. Petroleum is nowhere found in commercial quantities in the Salifère, although it everywhere contains oil, but wherever suitable beds of later age unconformably overlie, or recline against the Salifère, the former contain oil, often in enormous quantities.

Lewis Hamilton resolutely supports the contentions of local geologists, after years of study of Roumania, and confirms the fact that the yield of oil from Meotic, Levantine and other Pliocene strata bears a very definite relationship to the structure and angle of unconformity between these and the underlying or flanking Salifère. All the great oil-fields of the country display the relationship, and this knowledge is successfully applied in the search for new fields. Further confirmation of the relationship is afforded by the fact that the upper Pliocene beds do not contain oil when not thrown into suitable flexures and brought into contact, or in proximity to the Salifère.

The source of Roumanian oil is thus apparently demonstrated, but its origin is less obvious, though popularly and naturally attributed to organic matter in the shales of the Miocene saliferous beds. Some disconcerting features connected with this hypothesis are given on pp. 272-74, and are worth perusal.

From California come equally emphatic assertions under the signature of that able enthusiast, Ralph Arnold, regarding the origin of oil in some of the fields of the state.[1] It is unequivocally asserted that the presence or absence of petroleum in the porous strata amidst the Miocene is dependent upon the presence or absence of the Eocene shales, and if the Eocene shales are present, then the abundance or scarcity of oil depends largely upon :—

(*a*) The proximity of the sand to the Eocene shales.
(*b*) The state of disturbance of the underlying Eocene shales, or their relative position, *i.e.*, whether conformable or unconformable to the overlying beds.
(*c*) The degree of porosity and grain of sand of the Junction Zone beds.
(*d*) The effectiveness of the barriers hindering the escape of the hydrocarbons from the oil sands.

Referring specifically to the Coalinga field, Arnold states that the productivity of the Miocene beds roughly varies inversely with their distance from the Eocene (Tejon) shales, and that productivity is greatest where the shales occupy a position of angular unconformity with the Miocene sands, or are more or less disturbed, as near the axis of an anticline.

At Coalinga the Eocene shales underlying the main productive series are largely composed of the tests of diatoms and foraminifera, and are everywhere petroliferous, their interbedded sands being productive of oil; and it is confidently assumed that the oil is derived from organic matter embedded in the shales. The cases of Roumania and California afford classical examples of sources of oil that are doubtless repeated elsewhere. Peru presents a case of shales of a certain age exhibiting traces of oil, and giving productions only on the comparatively rare occasions where interbedded with sands, and in Mexico, Texas, and Louisiana oil is in some districts confined to sedimentary strata encircling or lining bosses of volcanic rock or saline intrusions. Reference

[1] See Bulletin 357, United States Geological Survey.

is made to the diatomaceous and infusorial character of marls associated with Mexican domes by F. W. Moon.[1]

Further proof of the organic origin of natural petroleums is drawn from their optical activity shown when subjected to polarised light, a subject investigated by Rakosin. This latter property has been traced to the presence of cholesterol, which is essentially a constituent of animal fats, but in some cases phytosterol, the vegetable equivalent of cholesterol, and possessing the same optical properties, is found, thus indicating in such cases a vegetable origin. As cholesterol is said to be the more common optical product in oils, an animal origin[2] is generally preferred.

Vegetable Sources of Petroleum.—Accumulating evidence favours the opinion that vegetable matter may be the source of certain petroleums, although there is no justification for the uncompromising attitude of certain exponents of this theory. Two kinds of vegetable matter are possible, terrestrial and aquatic, and in the deltaic conditions that characterise so many oil-fields either could be equally well appealed to as a source of accumulation. The extensive coal and lignite deposits in many geological periods bear eloquent testimony to the presence of carbonaceous matter far in excess of that required to provide proved supplies of petroleum; indeed, the very abundance of such deposits which have not been converted into petroleum furnishes a strong argument against accepting a carbonaceous origin for petroleum.

That vegetable matter can be partially converted into bituminous compounds or hydrocarbons by natural processes is demonstrated in every important coal-field. Marsh gas (methane) often occurs in great quantities in faulted zones amidst the coal measures, but the bituminous substances found in coal are not true bitumens that dissolve in the usual solvents and emit the characteristic odour on burning. Tars derived from the destructive distillation of coal in no way resemble natural petroleums or the product of oil shales; but contain such products as benzine, toluene, phenols, pyridines, naphthalene, anthracene, etc. In this

[1] *Transactions Inst. M.M.*, 1910-11, "The Relationship of Structure and Petrology to Petroleum."

[2] Lewkowitsch, "Chemical Technology of Oils, Fats, and Waxes."

connection Professor Hewitt, F.R.S., an authority on coal-tar products, has favoured the author with the following views :—

Petroleum can scarcely be a product of the distillation of coal since it consists for the greater part of hydrocarbons of saturated series, either open-chain paraffins C_nH_{2n+2}, or naphthenes (*cyclo*-paraffins) C_nH_{2n}. Hydrocarbons obtained from the action of heat on bituminous coal consist in greatly preponderating amount of members of the aromatic series, benzine and its homologues, naphthalene, anthracene, etc. Associated with them are phenolic compounds in considerable proportions and other substances containing sulphur and nitrogen in smaller amount.

The argument may be urged that petroleum nearly always contains some aromatic hydrocarbons, which occasionally form an appreciable percentage of the whole, and that on the other hand, paraffins are found in practically all coal tars, the proportion of paraffin to aromatic hydrocarbons increasing as the temperature of distillation is lowered. Supporters of the coal distillation theory are, however, met by the difficulty of explaining the absence of any notable amount of phenolic bodies in petroleum, and the fact that by no lowering of the temperature of distillation of a real coal have tar oils been obtained in which aromatic hydrocarbons are represented by mere traces. And yet, a petroleum containing 20 per cent. of aromatic hydrocarbons (benzine derivatives) would at once attract attention as a rare occurrence.

Notwithstanding the great outstanding differences between petroleum, oil shales, and coal, it may be added, in favour of a vegetable origin for some petroleums, that actual petroleum and true bitumens have been found in small quantities in some coals; that solid paraffins have been extracted by means of pyridine and chloroform; and that low temperature distillations *in vacuo* or at low pressures have yielded petroleum hydrocarbons, including naphthenes. These latter results of recent research seem to indicate that, even when coal was the overwhelming product, at certain times and places the conditions were merging into those which could yield oil, or the macerated vegetable substance composing the essential constituent of oil shales. A little thought will show that such conditions and results on a small scale might have been reasonably anticipated if vegetable matter can form oil at all.

Cunningham Craig[1] has recently attributed the origin of oil to terrestrial vegetation accumulated under littoral or deltaic conditions, but the universal association of salt is totally ignored, and his similes with coal rather serve to condemn the theory

[1] "Oil Finding," by E. H. Cunningham Craig. (E. Arnold.)

he advocates. Certainly few of his deductions fit in with observations made in existing oil-fields, and exception can be taken to his conclusions in Trinidad, where, in one important oil-field of that island, petroleum is contained in lenticles of sand embedded in foraminiferal clays containing no traces of vegetable matter. The acknowledged lenticularity of oil sands is sufficient explanation for wide differences in the character of particular horizons within short distances.

It is an observed and constantly commented-on fact that coal-fields and oil-fields are nowhere coincident. In the chief region where they are remotely associated, namely, the Appalachian field of America, the two horizons are absolutely distinct, and the coal seams are used as a reliable index of depth in the search for oil and gas beneath. In Assam, coal occurs in the oil series, but as coal, and shows no relationship to oil, and in many oil-fields carbonaceous matter abounds, but always as such, and rarely in contact with oil seams.

The author has seen tons of lignite ejected by a flowing well sunk into the Dacian beds of Roumania, but it is well known that the contained oil was a product of migration, and not formed in the Dacian. Unchanged carbonaceous matter occurs in the Russian oil-fields; and in Peru and California large deposits of tree trunks displaying no trace of oil occur in the oil series.

Terrestrial vegetation in a finely divided state, deposited under certain conditions, might provide material, within limited areas, for the production of oil, but it is not lignite and coal that can be appealed to, as all investigations tend to indicate that lower forms of vegetable life, such as algæ, which are enormously abundant, very prolific, and which could flourish in saline waters under almost all climatic surroundings, are a more probable source. Under such conditions low forms of animal life could participate, thereby promoting a possible dual origin.

Experiments by Krämer and Spilker on mud from the Gulf of Stettin revealed the possibility of extracting from it paraffin bodies resembling ozokerite,[1] and muds collected from the Gulf of Suez and the Mediterranean have yielded traces of petroleum

[1] "Ber. deutsch Chem. Ges.," 1900, XXII.; 1902, XXXV.

in association with sulphur and ammonia. The oil is thought in part to be derived from algæ. Certain bitumens considered to be associated with petroleum, found on sandy plains near Inhambane, Portuguese East Africa, have been attributed to accumulations of certain species of algæ.

Messrs Wade and Illingworth[1] have studied some odorous muds collected amongst coral reefs in the Gulf of Suez, where the water often recorded a temperature of 40° C. These muds were found to consist mainly of such organisms as foraminifera, sponges, algæ, seaweeds, with other microscopic organisms. From this mud was extracted, at 60° F., measurable quantities of an oily substance of sp. gr. 1.013 emitting a true petroleum odour. The results confirm other data, but it is advisable to accept with caution any products collected within the region of known oil-fields, as exuding petroleum from outside sources may be absorbed by certain bodies, and confuse the issue.

In a salt marsh, in the Hundred of Malcolm, South Australia, there is a marginal deposit 30 in. thick of "Mudoil" and "Indurite" (?) which, according to G. A. Goyder, consists of decomposing diatoms in mud and sand. Hoefer thinks this an intermediate product between diatoms and oil, deserving study.

Animal Sources of Petroleum.—Nature provides quite as many examples of accumulations of animal life as of vegetable, but with both certain essentials must be fulfilled to prevent the total decomposition of the fatty or resinous parts. The larger forms of life are naturally too scarce to admit of inclusion in any theories, and even fish life could only rarely provide material for appreciable accumulations. Smaller forms of life are more readily preserved, and their highly prolific character would assist quick accumulations.

Exception is taken by one writer to an animal origin on the curious score that most dead animal matter is devoured, and refers to the prevalence of the death mark on the shells of molluscs he has collected, ignoring the fact that only

[1] "The Origin of Petroleum," by Arthur Wade and S. Roy Illingworth (*Mining Magazine*, August 1914).

a certain class of siphonated carnivorous univalves have the power of boring into other shells. Most univalves are vegetarians, and all bivalves live on infusoria or on microscopic plants brought to them by water currents which their own ciliary apparatus excites. Reference could be made to numerous fossil beds amidst oil zones where it would be difficult to collect amidst millions a dozen specimens showing evidence of attack in the way suggested.

Exception is often taken to the absence of phosphates if oil is derived from animal matter, and at first sight this appears a reasonable stricture. Phosphates are rarely found in fresh water, as calcium phosphate is insoluble, and other forms gaining admission would be quickly converted into that substance if calcium bicarbonate were also present in the water, as is almost invariably the case. Calcium phosphate is soluble to some extent in waters containing sodium chloride (or ammonium chloride or carbonate), consequently traces of phosphates might be expected in some oil-well waters if the oil were of animal origin. Unfortunately, there is little available evidence concerning the composition of oil-field waters beyond their salt contents, and examination might disclose the presence of phosphates. It is, however, in the strata from which the oil is derived that one would expect most indications of phosphates, and these have been studied even less than the waters. A further possible reason for the paucity or absence of phosphates in certain cases will appear in the section dealing with the absence of sulphates (see p. 269).

Phosphates have been found in the Baku oil sands to the extent of upwards of 2 per cent. of phosphoric acid, but if oil pools were the concentration of a considerable area of sparsely distributed oil, the quantity of phosphate at any definite point would be extremely small. In this connection it must not be overlooked that where oil is a migration product, as is generally the case to a greater or lesser extent, it is not in the beds in which oil is found that the search for phosphates should be made, but in the strata of their origin. It seems very unlikely that careful analysis would fail to disclose the presence of phosphates in such beds as, say, the Miocene of Roumania, or the Eocene of California, where

abundant evidence of marine animal life has been observed; or, indeed, in many of the clays in which the productive lenticles of oil sand are enclosed in so many oil-fields. The presence or absence of phosphates in strata might probably, in some cases, fix the indigenous or adventitious origin of their oil contents.

Petroleum need not necessarily have been derived from animal matter that left visible traces of its structure behind. In the process of formation, such matter may have disappeared entirely, the carbonate of lime of shells or skeleton passing into solution, the organic portions being converted into petroleum.

The association of petroleum with fossil beds has been remarked upon repeatedly, but it is easy to place misconstructions on such data without knowledge of the fullest details of their occurrence. Thus in Roumania bucketsful of the shells of certain molluscs are withdrawn from oil wells with the sand, but no scientific value attaches to the fact, as the oil is not indigenous to the strata in which they occur.

Richard Bright,[1] in 1811, described a Liassic limestone in the neighbourhood of Bristol, England, from which petroleum sometimes exuded, a very unusual phenomenon in England. The rock contained large quantities of the remains of crustaceans, corallines, and encrinites. In the Kuban district of Russia, it is recorded by Winda that petroleum impregnations are exclusively confined to a series of Oligocene strata where the remains of fish are abundant, and that where these fossils are absent, neither the clays nor the neighbouring sands are petroliferous. The main oil sources of Peru are confined to a series of strata remarkably rich in fossil beds.

The absence of nitrogenous matter in oil is frequently commented on, but it is far from certain that many shales would not yield ammonia on destructive distillation. Typical oil shales of commercial worth are known to have no relationship with oil-fields, although they are frequent in coal measures. These shales always provide ammoniacal liquor on distillation, and the entire absence of even microscopic traces of organic matter provides an instructive example of the extent to which traces of oil-producing

[1] *Transactions Geol. Soc.*, IV. 199.

organisms, either animal or vegetable, can be absolutely obliterated by the processes of Nature.

Nitrogen is frequently present in natural gas from oil and gas fields, at times forming over 80 per cent. of its composition,[1] and its occurrence may be much more extended than usually supposed in crude oils. Its presence has been noted in American, Russian, and Algerian crude oils. Crystals of ammonia carbonate have been collected from gas wells near Pittsburg, and nitrogen has been found and estimated in Trinidad asphalt.

Leonard V. Dalton is inclined to attach to limestone oils an animal origin from geological considerations alone,[2] but this conclusion is perhaps too sweeping, as such porous bodies as dolomites are convenient receptacles for oil from outside sources. If the oil is indigenous to the limestones, terrestrial vegetation is quite outside consideration, and even other forms of vegetation are doubtful.

Theories of Oil Formation from Organic Matter.—In considering the organic origin of petroleum, it is idle to disguise the absence of co-operation between geologists and chemists. The study of the origin of petroleum demands the highest skill in both branches of science, and unfortunately the chemists have often been led astray by their ignorance of geological conditions. Increasing volumes of literature, detailing with great precision features observed in widely separated oil-fields, cannot fail to stimulate study in a branch of science which has hitherto perplexed so many people.

One writer goes so far as to state that unless the origin of the oil is known geological study is wasted and capitalists should refrain from risking their finances. Advice of this kind is quite gratuitous, as in no case yet has the origin of oil in any field been clearly established. Many of the greatest oil-fields of the world were discovered and worked before geologists or chemists were aware of the elementary conditions that promote the accumulation of oil.

A terrestrial vegetation theory of the origin of petroleum is

[1] See Vol. IX., "United States Geological Survey of Kansas."

[2] "On the Origin of Petroleum," *Economic Geology*, Vol. IV., No. 7, 1909.

abundant evidence of marine animal life has been observed; or, indeed, in many of the clays in which the productive lenticles of oil sand are enclosed in so many oil-fields. The presence or absence of phosphates in strata might probably, in some cases, fix the indigenous or adventitious origin of their oil contents.

Petroleum need not necessarily have been derived from animal matter that left visible traces of its structure behind. In the process of formation, such matter may have disappeared entirely, the carbonate of lime of shells or skeleton passing into solution, the organic portions being converted into petroleum.

The association of petroleum with fossil beds has been remarked upon repeatedly, but it is easy to place misconstructions on such data without knowledge of the fullest details of their occurrence. Thus in Roumania bucketsful of the shells of certain molluscs are withdrawn from oil wells with the sand, but no scientific value attaches to the fact, as the oil is not indigenous to the strata in which they occur.

Richard Bright,[1] in 1811, described a Liassic limestone in the neighbourhood of Bristol, England, from which petroleum sometimes exuded, a very unusual phenomenon in England. The rock contained large quantities of the remains of crustaceans, corallines, and encrinites. In the Kuban district of Russia, it is recorded by Winda that petroleum impregnations are exclusively confined to a series of Oligocene strata where the remains of fish are abundant, and that where these fossils are absent, neither the clays nor the neighbouring sands are petroliferous. The main oil sources of Peru are confined to a series of strata remarkably rich in fossil beds.

The absence of nitrogenous matter in oil is frequently commented on, but it is far from certain that many shales would not yield ammonia on destructive distillation. Typical oil shales of commercial worth are known to have no relationship with oil-fields, although they are frequent in coal measures. These shales always provide ammoniacal liquor on distillation, and the entire absence of even microscopic traces of organic matter provides an instructive example of the extent to which traces of oil-producing

[1] *Transactions Geol. Soc.*, IV. 199.

and other sulphur compounds in the petroleum and gases, and of iron pyrites in the oil-bearing beds, must be accounted for.

7. A plausible reason for the high gas pressures usually encountered must be offered.

(1) No direct proof is available regarding an adequate supply of organic matter, as where petroleum has been formed all essential organic material has disappeared in the process of conversion. Coal and most terrestrial vegetation scarcely require consideration, as the former was produced from the latter under circumstances quite inapplicable to petroleum. The small quantities of vegetation washed from the land might add to other sources of supply.

Petroleum-producing conditions must have originated under water, and this water must generally have been more saline than ocean waters, consequently marine organisms appear a necessity for such large quantities of organic matter as it is necessary to assume.

Open oceans do not provide the essential conditions, although the aggregate quantity of organic matter would suffice. Freedom of dispersal of organic living forms would lead to no accumulations of their bodies; indeed, the beds of oceans far from land receive little deposit of any kind.

An inland sea, large gulf, or a lagoon, where all inorganic and organic washings from the land must accumulate, where wide margins of shallow warm water favour the growth of aquatic vegetation, where forms of animal life restricted in genera and species and prodigious in numbers flourish, and where, in comparatively stagnant water, microscopic forms of animal and vegetable life abound, would appear to furnish, after the lapse of long periods of time, adequate material for the production of the oil found in specific areas.

On the eastern shore of the Caspian is a large gulf, named Karaboghaz, separated from the open sea by a mere strip of land, and whose only communication with the open sea is by a narrow channel about 150 yds. wide and 5 ft. deep, through which a continuous but fluctuating stream of water flows, at a rate averaging 3 miles per hour, the current being entirely due to the great evaporation in a confined shallow area. The total

area of Karaboghaz is about 8,000 sq. miles, and Von Baer, who has especially studied the Caspian, estimates that no less than 350,000 tons of salt are daily abstracted from the sea by this basin alone. As there are many other similar basins of smaller dimensions on the eastern and southern shores of the Caspian, and on the northern shores enormous lagoons where salt is deposited in a manner very like that at Karaboghaz, a reason is found for the brackishness of the Caspian, and an explanation is forthcoming for the intense salinity of some of the strata fringing the coasts.

Into this huge basin are swept daily thousands of fish, which cannot survive the intense salinity of the water, and whose remains must be deposited together with other sedimentary matter. The Russian Government has under its consideration a scheme for closing the channel to this basin in order to save the fish. Violent sandstorms periodically sweep the region of Karaboghaz, and one is led to inquire whether the deposition of huge quantities of fish remains known to be oily in a deposit of salt, and probably sulphate of lime, where practically the only siliceous matter is sand conveyed by winds, is not forming the material for a future oil-field, not very unlike the existing oil-fields.

The same phenomena may be proceeding elsewhere on a much less impressive scale, yet under conditions likely to lead to not only accumulations of oil, but also to the formation of geological facies typical of oil-fields. Thus Roswell H. Johnson,[1] commenting upon the rôle of barrier beaches and salt marshes, says: "The south shore of Long Island is very low, and edged with sedgy marshes. For a long distance a barrier beach of sand, similar in texture to our best oil sands, lies from one to three miles from the shore. The intervening lagoon communicates at occasional inlets with the ocean. It supports a rich flora of eel grass and algæ, and an accompanying fauna. The resulting deposits are black and grey muds and clay, often odorous with the decay of plants and animals. The conditions are just such as would be expected to produce elongated sand bodies, contiguous to organic shales."

That the accumulation of animal remains in such lagoons may

[1] *Economic Geology*, Vol. VI., p. 810.

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been struck in Trinidad (93° F.), and the Grosny (117° F.) and Cheleken oil-fields of Russia. At Kaiakent, near Derbent, in the Caucasus, hot malodorous sulphur water issues from the earth in an oil region, and the springs have long been frequented by peasants seeking relief from rheumatic complaints.

Further evidence of occasional high temperature has been disclosed in the periodical discovery of burnt shales, referred to on p. 194. The porcelainite of Trinidad (illustrated in Fig. 23) and the burnt shales of Barbados, associated with the oil-fields of these islands, have only been examined at or near the surface, but they may continue to a considerable depth. Similar burnt red shales are mentioned by Arnold and Claridge as occurring in the Santa Maria district of California, and are also recorded as being found in deep wells, showing that a high temperature was developed, and even combustion could proceed without the aid of air and at great depths.

Notwithstanding these concessions to high temperature reactions on organic matter as a source of oil, they must be regarded as exceptional and possible, and not as general and certain; indeed it can be proved in many cases that oil formation preceded the igneous intrusions or earth movements that might otherwise have been postulated as the cause of oil formation from organic matter at high temperatures. In other words, so far as present evidence goes, in order to account for oil formation from organic matter, we must not call in temperatures beyond the highest earth temperature due to depth of the rocks from which the oil was derived, which certainly never reached the destructive distillation point at the pressures also involved by the same depth.

But there are only two low temperature reactions known that are capable of forming hydrocarbons from carbon; one where an alkali metal or a metal of the alkaline earths is present to take precedence of carbon in the demand for oxygen, with the concomitant obligation to the latter of having to be satisfied with liberated nascent hydrogen, as when calcium carbide is placed in water and yields acetylene—a reaction it is quite impossible to consider in the case of petroleum being derived from organic matter. The alternative is direct or indirect bacterial action, which is not only possible, but for many reasons probable.

(3) It is well known that organic matter, even that most susceptible to decomposition, can be preserved indefinitely by sterilisation and total exclusion of air, which means protection from the attacks of bacteria; that is to say, dead organic matter has no inherent tendency to spontaneously break up.

Under normal sub-aerial conditions, such as exist in soil, organic matter will gradually be converted, by aerobic bacteria, into simple, oxidised, inorganic bodies, such as carbon dioxide, water, ammonia (passing into nitrates), and ash, the same materials from which it was originally formed directly or indirectly. But when free oxygen (ordinarily supplied by the air) is deficient, or absent, quite different products result; the action is still bacterial, but anaerobic bacteria take the oxygen they require for their life functions from compounds containing it; that is to say, they deoxidise them, and in doing so generate quite different bodies, hydrides being particularly in evidence, such as hydride of phosphorus (phosphoretted hydrogen), hydride of sulphur (sulphuretted hydrogen), and hydrides of carbon (the hydrocarbon marsh gas, the first member of the paraffin series, especially). It is highly probable that enzymes, products of bacterial action, are largely concerned in the chemical actions. In any case the result is a complete transformation of the original animal and vegetable substances, as is evidenced by every stagnant pond or septic tank.

(4) Supposing bacterial or enzyme action is admitted as a main factor in the production of petroleum from organic matter, all difficulty concerning the common or general absence of nitrogenous compounds in the oil or associated waters disappears; for whereas under aerobic conditions nitrogenous matter in decomposing tends to pass through the stages, ammonia, nitrites, and nitrates, under anaerobic conditions nitrites or nitrates are broken up, and nitrogen is set free as a gas. In this way much of the easily decomposable nitrogenous matter might disappear before burying up of the other organic matter, but evidently at times it did not, for nitrogen is often very largely in evidence in oil-well gases (see p. 261), indicating not only the presence of nitrogenous bodies in the original buried organic matter, but also a continuation of processes after covering up similar to those taking place before covering up took place.

(5) *Salt.*—On account of the very frequent excessive saltness of the waters associated with petroleum, many attempts have been made to enrol salt as a factor in the transformation of organic matter into oil. For instance, Professor Mrazec has stated that experiments have proved that in the water of the Bay of Naples carbon in the form of hydrocarbon is present in considerably larger quantities than carbon in the form of carbonic acid gas, which phenomenon he attributes to the saltness. Further, he says, from the chemical point of view, judging by the investigations of Kuenkler and Schwedhelm, the action of salt water must be of a saponifying nature, namely, the salts of the fatty acids are decomposed and hydrocarbons set free.

Another view of the active intervention of salt is that of a preservative, a retarder of decomposition in organic matter, thereby permitting of the burying up of the matter before complete dissolution.

Whilst not losing sight of these possible or probable effects, it is here suggested that the "rôle" of salt is mainly of a different character.

(*a*) It is a well established fact that fine sedimentary matter will sink more rapidly in salt water than in fresh, for some reason which is at present rather obscure, but attributed to the formation of a colloid.

(*b*) Fine sedimentary matter has a knack of attaching itself to minute, microscopic, and perhaps individually undetectable oil globules suspended in water (*cf.* "Emulsion," p. 504, Plate XXXIV.), and in sinking would naturally carry down these and decomposed or decomposing organic matter that might otherwise float on the surface or remain in suspension; probably the process by which great quantities of oil discharged on to waters with which it is not miscible is got rid of. Salt here would act mainly as an accelerator of deposition of organic matter, but it may also act in some of the other ways indicated above.

(*c*) But, in connection with the main purpose of this consideration of the origin of petroleum, salt, or a highly saline water, is primarily an indicator of the previous existence of those conditions which would lead to the accumulation of organic

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the formation of iron pyrites in the ferruginous muds is easily understood. The presence of sulphur dioxide in the oil and gases, of free sulphur in the rocks, and even the oil occasionally, and of peculiar sulphur compounds with constituents of the oil, do not admit of specific explanations. Some waters associated with petroleum are acid, probably due to oxidation of iron pyrites in rocks deficient in calcareous matter to neutralise the free sulphuric acid contemporaneously produced. Such waters coming in contact with unsaturated hydrocarbons would form additive compounds that would give off sulphur dioxide. Sulphur dioxide and sulphuretted hydrogen reacting would produce water and free sulphur. But the following paragraph very much discounts such an explanation as a general one.

It is interesting to note that limestone oils nearly always contain excessive quantities of sulphur compounds which impart to them a disagreeable odour, and to the associated gases very poisonous qualities. Objectionable properties are also retained by the products of distillation, and special and difficult treatment is usually necessary to remove the responsible sulphur compounds before the oils can be marketed. The limestone oils of the Lima-Indiana and Canadian fields are examples, whilst those of some of the Texas fields, like Spindle Top, are renowned. The oil derived from limestones in Persia, the Jemsa field of Egypt, and certain of the Mexican fields, testify to this prevailing and far-reaching phenomenon. Many deaths have resulted in most of the above-named oil-fields from inhalation of the poisonous gases which accompany these oils in enormous volumes.

(7) The very high gas pressure encountered in so many wells, when the oil-bearing beds are first tapped, must mean that in the formation of oil the decomposition of organic matter was continued after its deposition and covering up by newer impervious strata. It may have been continued through long periods of time.

It is now generally admitted that bacterial action is directly responsible for the preliminary chemical actions by which organic matter is converted into oil, but there unanimity of opinion ceases. The changes themselves, suggested by Engler as a result of able

and persistent work in the laboratory, may be near the truth, but for the bringing about of these changes by Nature in the buried organic matter exceptional, violent, but ill-defined causes are called in. Is this necessary?

The purely chemical problem of oil formation is beyond the scope of this work, but the following tentative suggestions on the subject may be made.

No experimental data will support, or even admit, of the supposition that sterile organic matter would spontaneously undergo chemical changes so as to form oil under such conditions of temperature and pressure as the earth alone could have given to most oil-bearing beds; some inducing agent must also have been present, and a particular form of inducing agent, if vegetable matter, for instance, was to form oil and not coal.

The tendency of modern bacteriologists is to regard the enzymes which are the products of bacterial action as the main cause of observed chemical effects, by acting as catalysts. It may well be that the colloidal enzymes resulting from anaerobic bacterial action are buried with the organic material they are acting upon, and there continue their action, for there is no obvious reason why, as catalysts merely, they should cease to perform their functions so long as sufficient unstable organic material remains, and they themselves are not destroyed by heat, or inhibited by the products of their action.

That such is actually the case is rendered the more probable from the fact that the first result of anaerobic action on organic matter is marsh gas, and marsh gas is the ever-present gas from newly tapped oil sources, to which indeed more than any other the great pressures encountered are due, though nitrogen also is a result of the same actions, and is a very common attendant of the marsh gas, adding to the pressure.

Thus the actual hydrocarbon products would seem to depend upon (*a*) the nature of the primary organic matter; (*b*) the particular character of the catalytic enzymes; (*c*) the temperature and pressure reached before complete conversion; and (*d*) finally, the adjustment of constitution and proportions of the various hydrocarbons would depend upon both the actual pressure and

the amount of uncondensed gas. Increase of temperature probably only acted as an accelerator of the catalytic action.

The Relationship of Paraffin and Asphaltic Oils.—The view has constantly been expressed that, for chemical reasons, oils of a paraffin base have been derived from vegetable matter, and asphaltic oils from animal matter. A study of the relationship of asphaltic and paraffin oils would therefore assist in supporting or disproving this suggestion. Attention has already been called to the inexplicable occurrence of these two kinds of oil in the Carpathian oil-fields. Roumania and Galicia yield normally asphaltic oils of the usual character in numerous localities where the Saliferous series is developed, consequently this could be termed, without contradiction, the normal phase of the Carpathian oil. The geological sequence is well established, beds are easily recognised by characteristic fossils, thereby eliminating various sources of error.

Along one pronounced Roumanian anticline asphaltic oils are yielded by the Meotic in commercial quantities over a varying width of territory until Campina is reached, when the oil changes into a typical paraffin variety. Intimate association with the Saliferous series is maintained throughout, but development is not sufficiently concentrated to the east of Campina to discern the line of demarcation, and to show whether the change is gradual or sudden. The passage of the River Telega may represent some sudden change of structure.

Moreni lies on a long, well-defined line of flexuring, along which asphaltic oils prevail at numerous operated points, and it was not until Filipeshti was tested by a well carried through barren strata to the Meotic that paraffin-base oils were suspected. Only a few miles further to the west, at Moreni (Bana), the Meotic in proximity to a core of Saliferous strata again yields paraffin-base oil, but the upper strata of Dacian and Levantine age, also reclining against the same Salifère core, yield asphaltic oils.

Boryslaw-Tustanowice constitutes another example of paraffin-base oil being produced amidst typically asphaltic oil surroundings, the association with the same Salifère being maintained,

At Starunia, near Stanislau, ozokerite is mined, but no very productive oil-field has been developed.

In Russia several examples of the same kind occur. The western extension of the Grosny field yields paraffin-bearing oils, although for an operated distance of many miles, where wells have been sunk to a considerable depth, nothing but true asphaltic oils have been found. The only apparent difference is that the anticline pitches to the west, rendering drilling deeper. Water in greater quantities is found, the same geological sequence of beds appear to persist, and the structure shows no pronounced change.

Cheleken, on the Caspian Sea, off Krasnovodsk, yields paraffin-bearing oils and ozokerite, although the beds are of Apsheron age, the same as overlie the oil-fields of Baku, where common asphaltic oils are universal. At Neftiania, in the Maikop oil-field, ozokerite occurs, although the region provides almost exclusively asphaltic oils, and in the neighbourhood of Tiflis, at Ildokani and Tsarsky Kolodsi, paraffin oils are obtained.

Petroleum of a typical asphaltic variety contains quite considerable quantities of wax in Mexico, the unusual association of the heaviest class of asphaltic oil with paraffin wax introducing many difficulties in refining.

In the Peruvian oil-fields the usual oil yields no appreciable solid paraffins, but in the higher oil series, oils containing a fair percentage of paraffin scale have been found at Lobitos and Negritos. California now provides a sensation by the discovery of paraffin-base oils beneath the ordinary variety in the Eastside oil-field of Coalinga. It is said that in Borneo paraffin-base oils were struck beneath the asphaltic type on one anticline. In the Minbu oil-field of Burma a dense viscous oil was struck containing no paraffin, although lumps of paraffin scale were raised with the detritus about the depth oil was struck.

The preceding facts indicate the close association of asphaltic and paraffin-base oils, and emphasise the advisability of hesitating to attach to the two classes a distinctively different origin. If the two varieties are derived from different material, the circumstances attending its deposition must bear a close resemblance.

Nor is this latter surmise difficult to believe, as the conditions which supported vegetable life might equally sustain certain forms of animal life, whilst their relative points of deposition in an area might be different.

Repetition of structure does not avail in seeking a reason for the different oils, as no two fields could present more dissimilar structures than Filipeshti and Moreni. Association of certain junction beds provides no plausible explanation, as in the Carpathians the oil is concentrated in the contact region of the Salifère with more recent beds, but the two qualities of oil are not confined to beds of any particular geological series.

Considerations of depth fail to elucidate any relationship with the nature of oil. In certain cases paraffin oils occur high in the geological sequence, as in Peru, Campina, and Grosny, and in other cases low, as in Filipeshti, Borneo, California. One point is worthy of record, however, although it may be merely a coincidence, that in no case known to the author has asphaltic oil been found beneath paraffin-base oil in the vertical geological sequence of oil-impregnated strata *within the confines of a single pool.*

Paraffin and asphaltic base oils appear indiscriminately amidst the same geological formation in Burma. Yenangyaung and Singu provide normal paraffin varieties, but the strata of the same age at Minbu and Yenangyat yield oils devoid of paraffin. The problem of their relationship is not simplified by the discovery of lumps of paraffin wax in a Minbu well yielding a typically asphaltic oil the same as other wells in the vicinity.

Whilst very inconclusive, the above facts rather tend to support the opinion that both paraffin and asphaltic oils have either a common origin, or are closely allied, and their different chemical constitution is due to other causes connected with their modes of formation or concentration.

Relationship of Grade of Oil to Depth.—Repeated attempts have been made to establish some relationship between quality or density of petroleum and depth. The density of oil has popularly been regarded as connected with depth, some observers considering light crude oils to be purified products of deeper,

heavier types, others maintaining that heavy oils are the product of lighter varieties deprived of their more volatile constituents. Depth, in this connection, is variously considered with relation to a fixed datum line, depth beneath surface or relative position in a geological sequence of rocks, according to which suits the local conditions under discussion.

Within restricted areas relationships can undoubtedly be traced, but considered on a larger general scale neither theory will hold good, however applied. Thus light oils are found at very shallow depths where least suspected, and are underlain by heavier varieties. Light oils are found beneath much heavier grades, and both light and heavy are found indiscriminately dispersed in a geological sequence.

That proximity to surface does not necessarily depreciate quality is clearly demonstrated by such fields as Tabaquite, Trinidad, where consistent yields of oil of a density of .790 (47° B.) with 40 per cent. petrol, have been obtained at an average depth of only 350 ft.; and by some of the Sumatra oil-fields, where large supplies of .756 (55° B.) oil are obtained at 400 ft. Petroleum of a density of .800 (45° B.) containing 40 per cent. benzine has been extracted in great quantities from depths of from 400-700 ft. in the Moreni (Bana) oil-field of Roumania; and at Surakhany, to the south-east of the Saboontchy oil-field of Baku, enormous gushers of .785 (50° B.) gravity oil, containing 48.9 per cent. of benzine and 43.9 per cent. of kerosene, were obtained at depths of less than 1,000 ft. In the Negritos oil-field of Peru oil of a density of .790 (47° B.), containing 35 per cent. of benzine, was regularly obtained from one area of development at 500-1,000 ft.; and in the Maikop oil-field of Russia crude oil containing 30 per cent. of benzine was obtained from a sand no deeper than 300 ft.

Petroleum of fairly regular density and constitution frequently saturates numerous sands through a considerable thickness of strata, the oils higher in the geological series and occurring at inconsiderable depth from the surface closely resembling those struck at a depth of 2,000-3,000 ft., and low in the geological sequence. In several of the Californian oil-fields sands impregnated

with heavy oils, or even tar sands, are underlain by sands containing lighter density oils, and the same feature was noted in the Guapo field of Trinidad. A heavy oil stratum overlies the rich light oil horizon of the Maikop oil-field; and the lightest oils of Galicia, in Bitkoff, having a density of .764 (54 B.), are struck at a depth of 1,800-2,000 ft.

On the other hand, beneath the light oils of Surakhany were struck the normal .880 (29° B.) density Baku oils; and in the Sumatra oil-field, already alluded to, the density of oil rose with depth to .773 (53° B.) at 800 ft., and .800 (46° B.) at 2,300 ft. Beneath the light oil horizon of Moreni (Bana) was struck at 3,000 ft. denser paraffin-bearing oil in a different geological series. The Moreni (Bana) field presents the unusual spectacle of three widely differing grades of oil being commercially developed in a field no larger than a *hundred* acres, viz., on the northern flank of the anticline shallow light oil and deep paraffin-bearing oils; and on the southern flank typical Moreni oil.

The light oils of Peru, to which reference has been made, are found in strata high in the geological sequence, sufficient unimpregnated strata lying between these beds and the deeper heavy oil horizons to preclude any relationship. Oil from the Minbu oil-field of Burma is of a much less volatile and denser quality than other oils of Burma, although occupying an almost identical relative position in the geological sequence.

Composition and Characteristics of Petroleum and Natural Gas.—Crude petroleum as it is found in Nature usually has a density of from .820-.940, although much lighter and much heavier varieties are occasionally met with. Some asphaltic oils are as heavy as water, their excessive viscosity giving them little commercial worth. Natural oils of a specific gravity of only .770-.780, often known as "white" oils, are sometimes struck in fair quantities, having apparently suffered some process of natural purification in the earth.

Freshly withdrawn petroleum emits a distinct but pleasant odour, unless contaminated with sulphur compounds, when it may be very objectionable and even offensive. Light constituents such as benzine usually emit a sweeter smell than

those less rich in volatile contents. Viewed by transmitted light, crude oils show a wide range of colour from amber, yellow, green, reddish brown, and through shades of brown to almost black, and under reflected light most exhibit a greenish colour, some in sunlight appearing a vivid green ; that is to say, crude petroleum is mostly dichroic. Unruffled surfaces of petroleum reflect objects in a wonderful manner, and in consequence enormous numbers of insects and even birds lose their life through mistaking surfaces of oil for water, after settling on its surface the viscous material preventing the use of their wings.

A curious phenomenon observed in some hot countries is the retention of a shadow on an oil surface after the object throwing the shadow is removed. This is attributable to the influence of fierce solar heat on freshly extracted oil, a shadow cast on the surface protecting that shaded portion of the oil, and causing thereby an unequal evaporation, and consequently unequal coloration of the oil.

The so-called "white" oils occasionally met with in oil-fields are usually transparent and amber tinted, and are evidently infiltration products of darker varieties which are usually found in the neighbourhood. They are rarely found in considerable quantities, but the author is inclined to believe that they are very commonly struck in small quantities during the drilling of wells, although only occasionally recognised by the drillers on account of their admixture with slush, and their resemblance to the dirty waters raised from the well.

It has been proved experimentally that dark crude oils can not only be deprived of their colour by forced filtration through fuller's earth or clay, but that a certain fractionisation can be accomplished also. There is no doubt that a similar natural process has proceeded in the earth where the white oils are found in the clays separating strata yielding dark oils.

Occasionally considerable quantities of the "white" oils have been found, but the only district which has regularly yielded this type in great quantities is Surakhany, on the outskirts of the Romany oil-field of Baku, where wells yielding as much as 48 tons of white oil daily have been struck, but even there the

relationship with the darker crudes has been established by the discovery of important deposits of the ordinary Baku oils at greater depths. A sample of Surakhany "white" oil, taken by the author from a flowing well which gave in one year about 10,000 tons of a similar oil, had the following characteristics :—

Colour :—Pale amber, clear and transparent.
Specific gravity :—.780.
Odour :—Ethereal and pleasant.

More than 50 per cent. distilled over below 150° C. and practically all was evaporated below 300° C.

A sample of "white" oil from the Los Angeles district of California, having a specific gravity of .810, yielded on distillation :—

Below 150° C. - - -	51 per cent.,	sp. gr. .783
From 150°-270° C. - - -	43 ,,	,, .834
Above 270° C. - - -	4 ,,	

Sumatra yields large quantities of volatile crude oils of the colour of port wine, with a marked absence of impurities and asphaltic or paraffin residues. Their densities vary from .750-.800, and from 50-60 per cent. of spirit is obtained by distillation. The Moreni (Bana) field of Roumania gave large yields of oil with a specific gravity of .800, yielding under distillation below 157° C. 50 per cent. with a density of .735.

Some crude oils of great purity and high viscosity, which realise in a crude state from £6 to £10 a ton ($4.20 to $7 per barrel), are found in the States of Wyoming, Texas (Jack County), Pennsylvania (Franklin), and West Virginia (Petrolia), in North America, and are employed direct as lubricating oils after filtration to remove particles of sand. One such black viscous Wyoming oil, of a specific gravity of 0.966, gave the following results on distillation :—

19.0	per cent. lubricating oil,	0.842 to 0.847	specific gravity.
45.0	,, ,, ,,	0.926 to 0.935	,,
12.5	,, ,, ,,	0.957	,,
14.5	,, coke.		
9.0	,, loss.		
100.0			

those less rich in volatile contents. Viewed by transmitted light, crude oils show a wide range of colour from amber, yellow, green, reddish brown, and through shades of brown to almost black, and under reflected light most exhibit a greenish colour, some in sunlight appearing a vivid green; that is to say, crude petroleum is mostly dichroic. Unruffled surfaces of petroleum reflect objects in a wonderful manner, and in consequence enormous numbers of insects and even birds lose their life through mistaking surfaces of oil for water, after settling on its surface the viscous material preventing the use of their wings.

A curious phenomenon observed in some hot countries is the retention of a shadow on an oil surface after the object throwing the shadow is removed. This is attributable to the influence of fierce solar heat on freshly extracted oil, a shadow cast on the surface protecting that shaded portion of the oil, and causing thereby an unequal evaporation, and consequently unequal coloration of the oil.

The so-called "white" oils occasionally met with in oil-fields are usually transparent and amber tinted, and are evidently infiltration products of darker varieties which are usually found in the neighbourhood. They are rarely found in considerable quantities, but the author is inclined to believe that they are very commonly struck in small quantities during the drilling of wells, although only occasionally recognised by the drillers on account of their admixture with slush, and their resemblance to the dirty waters raised from the well.

It has been proved experimentally that dark crude oils can not only be deprived of their colour by forced filtration through fuller's earth or clay, but that a certain fractionisation can be accomplished also. There is no doubt that a similar natural process has proceeded in the earth where the white oils are found in the clays separating strata yielding dark oils.

Occasionally considerable quantities of the "white" oils have been found, but the only district which has regularly yielded this type in great quantities is Surakhany, on the outskirts of the Romany oil-field of Baku, where wells yielding as much as 48 tons of white oil daily have been struck, but even there the

steady distillation ensues without periods of intermission as the temperature rises, until towards the end of the operation, when the heat is very great, only a small proportion of heavy residuum remains, which is converted into coke if the temperature is raised sufficiently high. By passing the evolved vapours through a condenser kept cool by means of a constant circulation of water, the various products may be condensed and separated into a mixture of hydrocarbons having boiling points and specific gravities between certain limits. Mixtures of hydrocarbons so condensed between fixed limits of density and flash point are given trade names under which they are marketed.

The isolation and determination of the hydrocarbons composing an oil is a very difficult operation, which is considerably complicated by (*a*) the existence of what are known as isomers, *i.e.*, hydrocarbons of identically the same quantitative chemical composition, but possessing different qualities on account of the different relationship of the atoms in the molecule; (*b*) the occurrence of a phenomenon termed "cracking," whereby during the process of distillation hydrocarbons of one composition are reduced to lower members of the same series, or even converted into other series of hydrocarbons. Oils of similar general character do not necessarily consist of a mixture of the same hydrocarbons; thus two oils yielding about the same proportion of equally good benzine, lamp oil, and lubricating oil may be composed of a mixture of quite different hydrocarbons belonging to totally distinct chemical series.

The chemistry of petroleum is exceedingly intricate, and there is no intention of entering into any description in this work, but a few details may give a general idea of the main characters of petroleum. Members of the paraffin series of hydrocarbons, C_nH_{2n+2}, form one of the chief constituents of oil all over the world, although the higher members which are solid at normal temperatures are comparatively rare, but methane, CH_4, the lowest member of the paraffin series, which is gaseous, is always present in large quantities dissolved in the oil, and it forms the chief constituent of natural gas.

Methane is a saturated hydrocarbon containing the maximum

percentage of hydrogen (25 per cent.) and smallest percentage of carbon (75 per cent.) by weight possible, and all higher members of the same homologous series contain a larger percentage of carbon and a lower percentage of hydrogen. Many of the finest oils in the world are composed largely of the normal paraffins (C_nH_{2n+2}), the higher members of the series being solid and known as paraffin scale after extraction.

The Russian oils of Baku appear to be largely built up of hydrocarbons known as naphthenes, being isomers of the olefine series, C_nH_{2n}, although there are many others, including the C_nH_{2n-6}, or benzine series, in the more volatile portion of some oils. Hurst has pointed out that the cause of the Russian oils having a lower flash point for a definite specific gravity than American oils is on account of the prevalence of naphthenes, which have a lower flash point compared with their specific gravities than either paraffins or normal olefines. So an approximate idea of the nature of the hydrocarbons composing an oil may be deduced from the relationship of specific gravity to distillation temperature and flash point.

Crude oils occasionally yield perceptible and sometimes appreciable quantities of aromatic hydrocarbons, benzine, C_nH_{2n-6} series, and their isolation can be effected for the preparation of nitrobenzine, the basis of many high explosives, and aniline, from which the aniline dyes are prepared. Selected oils from Borneo and Roumania are especially rich in the aromatic hydrocarbons, and their commercial extraction has been entertained from time to time.

Comparisons of specific gravity and the arbitrary designations of benzine, illuminating, and lubricating oils over a fixed range of temperatures of distillation give but an approximate idea of the actual constitution of the oil, although such divisions are useful for rough comparisons. It is usual, for general convenience, to adopt Engler's method of designating as benzine those products which distil up to 150° C. or 302° F., and as illuminating oils those distilling beween 150° and 300° C. (302°-572° F.). Such a rough separation is approximate only, but as a rule good lamp oils contain few fractions distilling

below 150° C., and few above 300° C., although all depends upon the character of the hydrocarbons. Russian kerosene contains fractions within close limits of 150° and 270° C., and some Roumanian crude oils yield 42 per cent. of good lamp oil between 130° and 310° C., with a specific gravity of only .808 after refining.

Table IV. gives the percentage by volume yielded by a number of crude oils from different oil-fields between 0°-150° C. and 150°-300° C., the specific gravity of the distillates being in most cases also given. A comparison will show the wide difference in volume and density of the distillates from different oils.

It will be found that the specific gravities and flash points of distillates from different crude petroleums within defined limits of temperature vary considerably; indeed, rarely do crude oils from two separated fields yield the same results, whilst often oils from adjacent wells have a totally different set of hydrocarbons. Isolated samples of Roumanian oils have yielded 29 per cent. of fractions below 80° C., whereas the usual percentage is 10-12.

Consistent results in distillations are difficult to attain unless every detail is closely reproduced in every sample. The rate of applying heat, and the kind and size of vessel, modify results, and by alternately raising the temperature and allowing it to fall again increased volumes between certain limits of temperatures are obtained.

Table V. has been prepared to illustrate the differences in character of the hydrocarbons composing the lighter fractions within the same range of temperature of four representative Roumanian oils, from which it will be noticed what a wide difference there is, not only in the percentage yield of the respective fractions, but also in the density of the products. The lighter fractions have been selected, as, owing to the lower temperature of distillation and the less complex character of the distillates, less decomposition will have taken place during the distillation than with oils of greater density.

The almost limitless possible number of hydrocarbons with their isomers, especially in the higher members of a homologous

TABLE IV.—COMPARISON OF REPRESENTATIVE CRUDE PETROLEUMS FROM DIFFERENT OIL-FIELDS.

Field from which Oil is taken.	Specific Gravity.	Distillate by Volume.					Remarks.
		0° to 150° C.		150° to 300° C.		300° C. and Above.	
		Per Cent.	Sp. Gr.	Per Cent.	Sp. Gr.	Per Cent.	
Pennsylvania	0.820	21.0	0.718	41.0	0.798	37.0	Edeleanau.
Ohio (Lima)	0.838	9.7	0.728	37.1	0.787	52.12	Mabery.
Illinois (Randolph County	0.842	14.0	0.729	37.0	0.797	49.0	2.40 °/₀ Sulphur.
Kansas (Wilson County)	0.835	19.0	0.720	38.1	0.808	42.8	... ...
Oklahoma (Glenn Pool)	0.846	8.5	0.756	42.0	0.800	49.9	6.98 °/₀ Paraffin.
West Virginia	0.787	16.5	0.711	41.0	0.769	34.5	5 °/₀ Paraffin.
Louisiana (Caddo)	0.925	...	...	17.0	0.841	82.9	U.S.G.S.
Wyoming (Natrona County)	0.826	11.0	0.721	36.0	0.793	50.0	U.S.G.S.
California (Coalinga)	0.915	5.7	0.771	34.1	0.858	60.2	0.45 °/₀ Sulphur. Cooper.
„ (Kern River)	0.961	...	...	20.2	0.862	79.8	0.94 °/₀ Sulphur. Cooper.
„ (Los Angeles)	0.971	...	...	26.3	0.885	73.7	1.18 °/₀ Sulphur. Cooper.
„ (Whittier Field	0.929	4.2	0.773	38.3	0.870	57.5	Prutzmau.
„ (Sunset)	0.972	...	...	12.0	0.844	...	U.S.G.S.
Texas	0.910	2.9	0.794	39.8	0.876	57.3	... ...
Russia (Grosny)	0.869	13.4	0.730	25.6	0.808	60.6	... ...
Roumania (Bushtenari)	0.842	35.4	0.734	29.8	0.840	34.8	Edeleanau.
„ (Campina)	0.824	37.7	0.729	30.5	0.823	31.8	Edeleanau.
Burma (Yenangyat)	0.840	17.8	...	49.4	...	...	Engler.
Italy (Villeia)	0.787	55.0	...	42.0	...	...	Light brown.
Japan (Echigo)	0.862	21.8	...	38.8	...	39.9	Paraffin. Mabery.

TABLE V.—PROPERTIES OF DISTILLATES BETWEEN 0° C. AND 150° C. OF FOUR REPRESENTATIVE ROUMANIAN PETROLEUMS.[1]

Temperature of Distillation.	Tetzeani.		Bushtenari.		Campina.		Baicoi.	
	Per cent by Weight.	Specific Gravity.	Per Cent. by Weight.	Specific Gravity.	Per cent by Weight.	Specific Gravity.	Per cent by Weight.	Specific Gravity.
Deg. Cent.								
0- 50	11.88	0.640	4.00	0.647	0.77	0.651	3.60	0.634
50- 60	4.29	0.666	0.70	0.668	2.40	2.679	5.95	0.658
60- 70	7.29	0.706	3.74	0.681	4.90	0.686	5.92	0.678
70- 80	4.95	0.725	4.25	0.707	3.85	0.705	4.62	0.696
80- 90	8.25	0.737	4.66	0.726	7.92	0.728	11.00	0.719
90-100	12.21	0.744	13.70	0.735	17.90	0.732	13.20	0.732
100-110	14.20	0.753	24.24	0.745	9.25	0.739	13.40	0.745
110-120	10.89	0.758	15.93	0.755	9.05	0.747	11.20	0.753
120-130	8.58	0.764	10.12	0.760	17.34	0.756	11.75	0.755
130-140	8.25	0.773	9.34	0.775	10.32	0.765	10.50	0.766
140-150	8.58	0.779	9.32	0.782	16.28	0.776	8.86	0.775

series, only a comparatively few of which have yet been isolated, presents endless combinations and possibilities. The boiling points and densities of the hydrocarbons increase with the complexity of the molecule, and many of the higher members of certain series have a specific gravity approaching unity, and their true boiling points cannot be experimentally shown owing to decomposition before it is reached.

Table VI. gives the percentage by weight of the fractions in five representative refined illuminating oils, with the specific gravities, flash points, and fire points of each fraction, which table also clearly illustrates the difference in character of the hydrocarbons composing lamp oils of similar general qualities from different sources used for the same purpose.

The paraffins are the most stable hydrocarbons, and to the special prevalence of this series may be attributed the superiority of Pennsylvanian lamp oils over many other varieties. The carbon affinities in the paraffin molecule are satisfied to the fullest extent with hydrogen, but where such is not the case, the

[1] Taken from "A Study of Roumanian Petroleum," by Edeleanau and Tanasesco.

TABLE VI.—RELATIONSHIP OF FRACTIONS BETWEEN 140° C. AND 300° C.,[1] IN FIVE REPRESENTATIVE ILLUMINATING OILS.

Origin and Characteristics of Oil.	American (Water White). Specific Gravity, .7954. Boiling Point, 125° Cent. Flash Point, 42° Cent. Fire Point, 55° Cent.				Russia. Specific Gravity, .825. Boiling Point, 130° Cent. Flash Point, 31° Cent. Fire Point, 47° Cent.				Roumania. Specific Gravity, .811. Boiling Point, 112° Cent. Flash Point, 26° Cent. Fire Point, 38° Cent.				Texas. Specific Gravity, .810. Boiling Point, 125° Cent. Flash Point, 30° Cent. Fire Point, 37° Cent.				Galicia. Specific Gravity, .812. Boiling Point, 110° Cent. Flash Point, 27° Cent. Fire Point, 39° Cent.			
Fractions up to	Per cent. by Weight.	Specific Gravity.	Flash Point.	Fire Point.	Per cent by Weight.	Specific Gravity.	Flash Point.	Fire Point.	Per cent by Weight.	Specific Gravity.	Flash Point.	Fire Point.	Per cent. by Weight.	Specific Gravity.	Flash Point.	Fire Point.	Per cent by Weight.	Specific Gravity.	Flash Point.	Fire Point.
Deg. Cent.			Deg.	Deg.			Deg	Deg.			Deg.	Deg.			Deg.	Deg			Deg.	Deg.
140	...	...	...	...	...	...	...	...	3.38	.766	...	...	...	...	..	...	1.65	.759	...	...
150	1.50	.756	...	...	2.77	.779	...	...	8.00	.733	...	...	3.33	.768	...	...	5.42	.764	...	...
160	2.49	.759	14	15	5.57	.784	...	...	13.60	.780	16	19	6.68	.777	...	...	6.16	.770	...	...
170	5.22	.766	22	23	9.39	.792	16	...	12.45	.7895	22.4	29	12.36	.790	17	18	9.70	.7775	21	24
180	7.29	.772	28	31	7.57	.802	24	30	10.48	.7975	33	39	13.73	.799	28	31	4.27	.785	26	30
190	8.55	.778	36	42	7.23	.809	33	40	7.00	.805	43	51	13.00	.810	38	42	4.96	.791	31	37
200	9.44	.784	45	53	6.98	.816	42	48	6.54	.813	52	59	11.48	.820	49	52	4.29	.796	37	42
210	8.22	.790	53	63	6.84	.823	51	58	6.24	.821	60	67	10.41	.830	59	63	4.24	.8015	44	50
220	7.89	.796	62	72	6.83	.829	59	67	5.67	.8285	67	75	9.52	.839	68	72	4.94	.808	51	57
230	7.74	.801	70	82	6.72	.8345	67	75	4.48	.836	73	80	8.50	.847	75	80	4.95	.813	59	67
240	7.02	.806	80	90	6.57	.839	75	84	4.28	.843	78	86	3.83	.855	82	87	4.96	.8185	67	77
250	6.37	.810	85	97	6.45	.843	83	92	3.62	.849	82	90	3.31	.863	88	94	5.16	.8235	75	84
260	4.50	.814	95	103	6.44	.848	91	101	2.91	.855	86	96	2.00	.870	94	100	5.30	.828	83	94
270	3.77	.818	103	109	6.20	.852	99	109	2.95	.861	90	104	0.82	.877	99	106	5.65	.833	92	102
280	2.77	.822	110	117	4.27	.857	107	117	2.55	.866	94	108	...	...	...	...	6.25	.8265	102	113
290	2.08	.826	117	124	4.12	.861	114	125	1.37	.870	97	114	...	...	...	...	5.10	.8405	113	124
300	1.63	.830	125	132	2.42	.8645	120	133	0.99	.873	99	119	...	...	...	...	4.70	.844	124	137
Above 300	3.52	.843	112	119	3.03	.878	143	158	2.90	.885	124	143	0.60	.892	...	...	12.20	.857	139	151

[1] From paper read before the Petroleum Congress in Liège, in 1902, by Dr Dvorkovitz.

hydrocarbons are said to be unsaturated, and become more so with the complexity of the molecule in each series of hydrocarbons. The saturated hydrocarbons can be separated from the unsaturated by sulphuric acid, and the less saturated the hydrocarbons the more readily are they attacked by sulphuric acid.

The refining of lamp oils is undertaken to remove the more unsaturated hydrocarbons, as they impair the combustion of the oil and lead to the emission of disagreeable odours. The saturated hydrocarbons are unaffected by sulphuric acid, but some of the unsaturated are decomposed by sulphuric acid, others unite with it to form sulpho-compounds. The less complex character and more saturated condition of the hydrocarbons in the most volatile fractions of most oils accounts for the diminished need for refining the lighter distillates of all crude oils.

Density of Oils.—The specific gravities of petroleum vary considerably, even in the same district of an oil-field, but whilst this is sometimes due to local geological conditions, in many cases the variation is due to such causes as the age of the well, presence or absence of water with the oil, extent of exhaustion of the strata, etc. There is usually a sensible increase in density of petroleum when pumped from the field to the storages, being equivalent in the case of light crude oils in a warm climate to a loss of 5-10 per cent. When stored for long there is a continual loss by evaporation from light oils which increases their density, and in warm climates the tanks should therefore be screened from the sun.

The specific gravity of oil in the United States is generally measured in degrees on the Baumé scale, but in most countries the density of oils is compared with water as unity. The specific gravity is almost universally taken on the field by a hydrometer, when the density is read off a scale directly, and corrections applied for temperature, etc., but where extreme accuracy is needed, either a specific gravity bottle, is used, or a set of hydrometers each of which indicates a narrow range of densities over a long scale, in which case a pilot hydrometer is included to indicate the approximate density, so that the correct instrument shall be selected without trial.

TABLE VII.—Table of Baumé and Specific Gravity Equivalents.

Baumé.	Specific Gravity.	Baumé.	Specific Gravity.	Baumé.	Specific Gravity.
10	1 0000	37	0.8395	64	0.7243
11	0.9930	38	0.8346	65	0.7205
12	0.9860	39	0.8299	66	0.7168
13	0 9790	40	0 8251	67	0.7133
14	0.9722	41	0.8204	68	0.7097
15	0.9658	42	0 8157	69	0.7061
16	0.9594	43	0.8110	70	0.7025
17	0.9530	44	0 8063	71	0.6990
18	0.9466	45	0.8017	72	0.6956
19	0.9402	46	0.7971	73	0.6923
20	0.9339	47	0.7927	74	0.6889
21	0.9280	48	0.7883	75	0.6856
22	0.9222	49	0.7838	76	0.6823
23	0.9163	50	0.7794	77	0.6789
24	0.9105	51	0.7752	78	0.6756
25	0.9047	52	0 7711	79	0.6722
26	0.8989	53	0 7670	80	0.6689
27	0.8930	54	0 7628	81	0.6656
28	0.8872	55	0.7587	82	0.6619
29	0.8814	56	0.7546	83	0.6583
30	0 8755	57	0 7508	84	0.6547
31	0 8702	58	0.7470	85	0.6511
32	0 8650	59	0.7432	86	0.6481
33	0.8597	60	0 7394	87	0.6451
34	0 8544	61	0.7357	88	0.6422
35	0 8492	62	0.7319	89	0.6392
36	0.8443	63	0 7281	90	0.6363

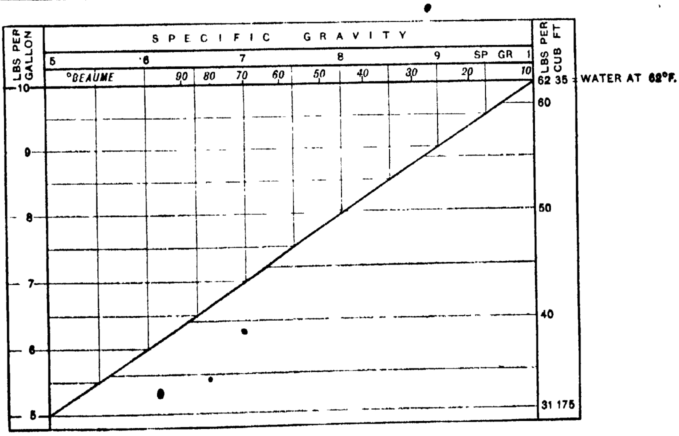

Fig. 43A.— Diagram illustrating Relationship of Baumé and Specific Gravity (compared with water) Equivalents, and giving Weights in Lbs. per Gallon and Cubic Feet.

Table VII. gives the Baumé and specific gravity equivalents.

A formula has been published by the American Bureau of Standards for converting Baumé into density compared with water, as under:—

$$° \text{ Baume} = \frac{140}{\text{Sp. gr. of liquid at } 60° \text{ F.}} - 130.$$

$$\text{Sp. gr. at } 60° \text{ F.} = \frac{140}{130 + \text{deg. Baumé}}.$$

The coefficient of expansion of petroleum not only varies with different classes of oil of the same specific gravity, but also with alterations of temperature, and the expansion of heavy oils is less than that of light oils. Owing to the variation of expansion with different oils it is usual to prepare tables to apply to special oils with which one is constantly engaged, giving the amount to be added to or subtracted from the observed specific gravity for each degree fall or rise of temperature below or above normal temperature, to reduce the specific gravity to normal temperature. The coefficient of expansion of crude oils varies between extreme limits of about .00085 for light grade crude, and .00065 per degree C. for heavier crudes (equal to .00047 and .00036 per degree F.), and these values, when accurately determined by experiment, are added to or subtracted from the observed gravities to reduce to some normal basis for comparison. At increased temperatures the rate of expansion increases slightly, but it is usually neglected in crude oil estimations. Sir Boverton Redwood gives the following corrections that should be made for refined products:—

Products lighter than Kerosene	.00040 to .00048	per 1° F.
Kerosene	.00040	„
Gas oils	.00036	„
Lubricating oils	.00034	„

Davis, in his "Petroleum Tables," which are generally used by shipowners for calculating cargoes of tank ships, gives the following corrections:—

For Benzine	.00045	per 1° F.
„ Lamp oils (.795 to .825)	.00040	„
„ Solar and light lubricating oils	.00038	„
„ Heavy lubricating oils	.00035	„

Tables IV., V., VI., VIII., IX., give the specific gravities of a number of representative oils from different countries.

Ultimate Composition.—The ultimate composition of crude petroleum varies very little indeed, the percentage of carbon ranging from 84-86, and that of hydrogen from 11.5-14.5. Sulphur largely enters into the composition of some oils, and there are often appreciable proportions of oxygen and nitrogen. Table VIII. gives a few ultimate analyses of petroleum collected from various sources.

TABLE VIII.—ULTIMATE COMPOSITION OF REPRESENTATIVE PETROLEUMS.

Origin of Petroleum.	Specific Gravity.	Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Sulphur	Authority.
Pennsylvania - -	0.801	86.10	13.90	..	...	0.06	Engler.
Ohio - - -	0.827	85.42	14.59	0.064	..	..	Mabery and Dunn.
California (heavy) -	0.984	86.32	11.70	1.25	...	0.84	Mabery.
,, (light) -	0.846	86.24	13.08	.	...	...	,,
Texas (Beaumont) -	0.912	85.03	12.30	0.92		1.75	C. Richardson.
Roumania (Bushtenari) - -	...	86.30	13.32	...	...	0.18	Edeleanau.
Roumania (Campina) - - -	...	86.03	13.26	..	...	0.13	,,
Canada (Petrolia) -	...	83.94	13.37	..	...	0.99	Mabery.
Peru (Zorritos) -	0.850	86.08	13.06	0.071	0.748	0.041	...
Italy (Parma) -	0.786	84.00	13.40	...	1.80	...	Deville.
Russia (Baku) -	0.884	86.3	13.6	...	0.1	...	Redwood.
Galicia - - -	0.852	85.3	12.6	...	2.1	...	,,
Burma . - -	0.855	83.8	12.7	...	3.5	...	,,
East Indies (Java) -	0.880	87.1	12.0	...	0.9	...	,,

Calorific Value.—The calorific value of petroleum can be found by calculation from the ultimate composition, or it can be directly determined by combustion in a calorimeter. The results very closely coincide, and either is always sufficiently near for all commercial purposes for which comparisons are required. Petroleum cannot be readily burnt in ordinary calorimeters owing to the fierceness of the combustion, even when well mixed with absorptive substances to delay the action. The Mahler bomb type of calorimeter is the only safe and reliable instrument to use for liquid fuels, and a description

of the method of use can be found in chemical works. In Table IX. are given the calorific values of a number of selected oils representing characteristic types.

Calorific values may be stated either in calories, which is the amount of heat required to raise 1 kilo of water 1° C., or in British thermal units, which is the heat required to raise 1 lb. of water 1° F. Calories per kilo can be converted into British thermal units per lb. by multiplying the former by 1.8.

TABLE IX.—CALORIFIC VALUES OF REPRESENTATIVE PETROLEUMS.

Nature of Petroleum.	Specific Gravity.	Calorific Value, B.T.U.'s per lb.
West Virginia	0.841	18,400
Louisiana	0.939	19,300
Californian	(?)	18,742
" (Coalinga)	0.932	19,000
"	0.948	18,675
Texas (Beaumont)	0.920	19,060
Russia (Baku)	0.884	20,600
Galicia	0.870	18,000
Roumania (Bushtenari) residue	(?)	19,600
" (Campina) "	(?)	19,900
Burma	0.869	19.250
Peruvian (Negritos)	0.850	19,445
Italy (Parma)	0.786	18,200

Flash Point and Fire Test.—As all petroleums evolve inflammable gases at certain temperatures, careful investigations have been undertaken for the purpose of framing legislation to protect the public. Petroleum, like water and many other liquids, suffers a certain amount of evaporation at temperatures far below the boiling points of the hydrocarbons composing the product; indeed, high winds will cause considerable evaporation of oil exposed to the atmosphere, and some oils can be entirely evaporated at a temperature below zero by blowing cold air through them. It was formerly usual to gradually warm a sample of oil in a small open vessel placed in a water bath, until a flash occurred when a lighted taper was held over the vessel. The temperature at which the flash took place was called the "flash point" of the

oil, and by continuing the heat a point was reached when the oil took fire, and this was termed the "fire point." There is a considerable difference between the flash point and fire point of oils, amounting often to 25°-30° F. in the case of illuminating oil.

Investigations showed that to obtain consistent results a system of testing would have to be standardised, as the flash point differed with the manner in which the test was applied. When made in an open vessel a much higher flash point was recorded than when tested in a closed vessel, the difference reaching usually 25° - 28° F. Eventually the Abel-Pensky flashing test instrument was introduced and accepted as a standard by the British and some other Governments, and tests properly conducted show uniform results, as the instrument assures identical conditions in every test. Corrections have to be made for variations of atmospheric pressure, the flash point being lower with increased altitude or fall of barometer. For each one inch of variation in the mercurial column there is a reduction or elevation of 1.6° F. in the flashing point. Full directions for use are given with flash-testing instruments, as well as tables of corrections for barometric pressure.

The British standard flash point for lamp oil is 73° F. by the closed test, equal to about 100° F. open test.

Natural Gas.—Natural gas is extensively employed for both heating and illuminating purposes, especially in the United States, where it is often conveyed hundreds of miles in large mains under a high pressure. Natural gas has a calorific value far exceeding that of coal gas

The United States Geological Survey gives the analyses and particulars of average quality natural gas from different gas-fields, shown in Table X., where for the purpose of comparison the analyses of artificial gases are given also.

Very complete investigations of West Virginian natural gas have been made by Professor Phillips of the Western University of Pennsylvania on behalf of the United States Geological Survey.

TABLE X.—ANALYSES OF CHARACTERISTIC NATURAL GASES AND COMPARISON WITH MANUFACTURED GASES.

Constituent.	Average, Pennsylvania and West Virginia.	Average, Ohio and Indiana.	Average, Kansas.	Average of Coal Gas.	Average of Water Gas.	Average, Producer Gas from Bituminous Coal.
Marsh gas, CH_4 -	80.85	93.60	93.65	40.00	2.00	2.05
Other hydrocarbons	14.00	.30	.25	4.00	.00	.04
Nitrogen - -	4.60	3.60	4.80	2.05	2.00	56.26
Carbon dioxide -	.05	.20	.30	.45	4.00	2.60
Carbon monoxide -	.40	.50	1.00	6.00	45.50	27.00
Hydrogen - -	.10	1.50	.00	46.00	45.00	12.00
Hydrogen sulphide	.00	.15	.00	.00	.00	.00
Oxygen - - -	Trace	.15	.00	1.50	1.50	.05
Total - -	100.00	100.00	100.00	100.00	100.00	100.00
Pounds in 1,000 cubic feet - -	47.50	48.50	49.00	33.00	45.60	75.00
Specific gravity, air being 1 - -	0.624	0.637	0.645	0.435	0.600	0.985
B.T.U. per cubic foot - - -	1,145	1,095	1,100	755	350	155

Table XI. is taken from this Report, and gives the analyses of nine representative samples of West Virginian natural gas.

An analysis of Pennsylvanian gas made by C. D. Howard, in which the hydrocarbons are distinguished, is given in Table XII.

TABLE XII.—ANALYSIS OF PENNSYLVANIAN NATURAL GAS (BIG INJUN SAND).

	Sample No. 1.		Sample No. 1.
Carbon dioxide (CO_2) - -	0.006	Ammonia (NH_3) - - -	None.
Carbon monoxide (CO) -	0.4	Carbon bisulphide (CS_2) -	"
Oxygen (O) - - - - -	0.2	Sulphuretted hydrogen (H_2S)	"
Hydrogen (H) - - -	Trace.	Moisture (grains in 100 cub. ft.)	17.72
Heavy hydrocarbons - -	0.4	Total sulphur (grains in 100 cub. ft.) - - - - -	0 182
Ethane (C_2H_6) - - -	14.60	Total paraffins - - -	95.54
Methane (CH_4) - - -	80.94	B.T.U.'s per cub. ft. - -	1142.6
Nitrogen (N) - - -	3.46		

From the great gas-fields of Surakhany, on the outskirts of the Romany oil-field of Baku, as much as 16,000,000 cub. ft.

TABLE XI.—ANALYSES OF REPRESENTATIVE WEST VIRGINIAN NATURAL GASES.

Constituents.	Fredonia.	Sheffield.	Kane	Wilcox.	Speechley.	Murrysville, Lyon's Run near.	Racoon Creek.	Baden.	Houston.
Nitrogen	9.54	9.06	9.79	9.41	4.51	2.02	9.91	12.32	15.30
Carbon dioxide	0.41	0.30	0.20	0.21	0.05	0.20	Trace	0.41	0.44
Hydrogen	0	0	0	0	0	0	0	0	0
Ammonia	0	0	0	0	0	0	0	0	Trace
Oxygen	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Sulphuretted hydrogen	0	0	0	0	0	0	Trace	0	0
Paraffins	90.05	90.64	90.01	90.38	95.42	97.70	90.09	87.27	84.26
	100.00	100.00	100.00	100.00	99.98	99.92	100.00	100.00	100.00
The paraffins contained in these gas samples have the following composition by weight:—									
Carbon	78.14	76.69	76.77	76.52	77.11	74.96	76.42	76.48	76.68
Hydrogen	21.86	23.31	23.23	23.48	22.89	25.04	23.58	23.52	23.32
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

of natural gas daily was at one time piped to the oil-fields for use as fuel in Lancashire boilers, but since 1909 there has been an inclination to disregard the gas, and drill deeper for the rich oil sources underlying the area. The composition of the Surakhany natural gas approximates to that of the American fields.

Table XIII. gives the analyses of several samples of Russian and other natural gases.

It will be observed that the Russian oil-well gases vary considerably in composition, and some contain large proportions of carbon dioxide and nitrogen. Wells yielding only nitrogen gas have been reported in America. Direct tests, made by Thompson and Hunter, of the volumes of gas issuing from bailing wells in the Russian oil-fields of Baku and Grosny, showed extremes of 20,000 and 130,000 cub. ft. a day, the average yield of nineteen wells in Bibi-Eibat being 43,200 cub. ft. a day. Actual tests of nineteen pumping and bailing wells in the Grosny oil-field showed extreme yields of 10,000 and 402,000 cub. ft. daily, with an average of 85,000 cub. ft. daily per well.

TABLE XIII.—ANALYSES OF RUSSIAN AND OTHER NATURAL GASES.

Origin of Gas.	CH_4	CO_2.	O.	N.	Other Hydro-carbons.	Authority.
Surakhany (Russia)	93.25	4.53	0.36	0.49	1.37	Baku Technical Society
" "	93.99	4.00	0.42	0.58	1.01	" "
" "	93.47	4.09	0.41	0.60	1.43	" "
Saboontchy (Baku)	66.90	28.50	0.80	3.20	0.60	" "
" "	72.30	18.40	1.80	6.80	0.70	" "
" "	51.90	37.80	1.40	6.50	2.40	" "
Bibi-Eibat "	82.20	12.80	0.80	3.00	4.20	" "
" "	58.40	22.80	3.80	14.40	0.60	" "
" "	86.33	9.96	0.19	0.72	28.80	" "
" "	87.80	8.40	0.20	0.70	2.80	" "
" "	89.00	9.80	0.10	0.30	0.20	" "
Grosny (Russia) -	56.30	6.90	...	9.60	25.40	Grosny Laboratory.
" " -	90.00	2.60	...	6.60	0.10	"
Taman Peninsula -	97.87	2.11	...	...	...	Bunsen.
Italy - - -	96.50	3.50	...	...	...	Schmidt.
" - - -	98.85	0.74	...	0.41	...	"
Canada (Ontario) -	92.20	1.40	...	5.59	?	Shuttleworth.

Enormous volumes of natural gas are allowed to escape into the atmosphere, and be permanently lost in the search for and development of oil-fields; nor can any reasonable project be devised for diminishing this loss to any considerable extent. The demand for light spirits has led to the installation of compressors for the liquefaction of constituents that can be kept liquid at moderate pressures, but they usually constitute a small percentage of the total, the bulk of the condensate being of the "wild" variety, and evaporating spontaneously on reduction of pressure. Methane, the chief constituent of natural gas, is uncondensable at all practicable temperatures and pressures, but ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), pentane (C_5H_{12}), and hexane (C_6H_{14}) can be liquefied at workable pressures and transported in steel cylinders. By intimately mixing these products with light refinery distillates, certain amounts are absorbed and retained, and under suitable circumstances their extraction and admixture can be made remunerative.

The lower the gas pressure in wells the higher the proportion of liquefiable gas, and when a vacuum of 12-14 lbs. per square inch is maintained in wells, a liquid product is often obtained without the aid of compressors or condensers.[1] In some oil-fields reduction of temperature on expansion of natural gas (from wells) in distributing mains will cause the condensation of light constituents.

Uses of Petroleum Products.—Some heavy crude petroleums containing a paucity of the more valuable products, and having a high flash point, are used direct as liquid fuel, and command a ready sale at a price 50 per cent. above that of good quality coal in any market in which they may be introduced. Texas and California furnish an abundance of such oils, and Russian oils yield a large percentage of fuel oils after extraction of some 30 per cent. of light or intermediate fractions. As fuel for boilers, however, oil can command but a low price, except in a few isolated cases where solid fuel is expensive; and operators in oil

[1] "Liquefied Products from Natural Gas," by Irving C. Allen and G. A. Burrell. Technical Paper No. 10, Dept. Interior, Bureau of Mines, Washington, U.S.A.

fields of medium productive capacity cannot remuneratively produce oil at such prices. It is usual to extract the lighter and more valuable portions of the crude for the production of petroleum spirit, illuminating oils, lubricants, and also paraffin wax when this latter is present. The combustion of liquid fuel is explained in Chapter XI., and the distillation and refining of petroleum is briefly described on pp. 299-306.

From some light crude petroleums, often with a flash point below 32° F. (0° C.), exceedingly light distillates can be obtained, which spontaneously evaporate when exposed to the atmosphere. Some such distillates have a specific gravity of only .590-.620, and are used as anæsthetics, solvents, cleaning solutions, and are employed in some types of carburetted air plants. The heavier spirits, of a specific gravity of .680-.750, are now extensively employed for internal combustion engines on automobiles, air craft, and motor boats, and in the highest grades fully 90 per cent. of the spirit has a boiling point below 100° C. The East Indian (Shell) spirit of .740 specific gravity has as low a boiling point as the American spirit of .700 specific gravity, demonstrating the wide difference in certain physical characters between two oils suitable for the same purpose.

The chief aim of oil refiners is generally benzine and illuminating oil, the latter having a specific gravity of .800-.820, boiling points between 150° and 300° C., and flash points of 70°-150° F. The distillates that can be included under lamp oils constitute from 50-70 per cent. of certain crude oils, whilst in some grades of petroleum not more than 15-30 per cent. of medium quality illuminant can be obtained. Purified oils of the character described will generally burn with complete combustion in a lamp by capillary action up a wick, provided ample air is suitably admitted for combustion, but modern ingenuity has devised means of vaporising not only lighter oils but ordinary lamp oils, and burning the gaseous products beneath incandescent mantles. By this system a greatly increased luminosity is obtained with a reduced expenditure of oil.

The .680 spirit can be used in the "Petrolite" lamp, which

consists of a porous block which absorbs the spirit and through which air is drawn, and thereby carburetted, by the natural heat of the flame. The carburetted air burns beneath an incandescent mantle, and the absolute safety of the lamp is assured by the absence of any loose liquid and the extinction of the flame at the instant the lamp is placed out of the vertical. The latest incandescent oil lamp is of the inverted type, and it is claimed that a unit of light can be obtained at a lower cost than by any other illuminant. With oil at sixpence a gallon, 1,000 candle power is estimated to cost three-eighths of a penny per hour.

Important use has been made during the last few years of carburetted air machines which automatically produce from benzine a combustible mixture of air and gas which can be led along pipes and burnt beneath incandescent mantles. The air only contains about 1.6 per cent. of hydrocarbon vapour, and will not burn unless broken up by passage through a special burner. The plant is worked by a small hot-air engine, and is automatically controlled to supply only the demand created. It is claimed that 1,000 candle power can be generated at a cost of $\frac{4}{5}$d. per hour. Improvements permit heavier products to be utilised for carburetting, but the real difficulty is to avoid the recondensation of the hydrocarbons.

Kerosene is largely used for heating stoves and cooking ranges, besides illuminating purposes, and in certain types of oil engines its use is general.

An intermediate distillate between illuminating and lubricating oils, known as solar oil, is largely sold for enriching gas made from low grade coal, and is especially used as the carburetting agent for the production of carburetted water gas in gas works. Water gas is produced by the passage of steam over incandescent coke, and it is carburetted to give it the necessary illuminating power. by mixture with the gas oils in hot chambers, when complete gasification is ensured. The solar oil here referred to is too viscous to properly feed the wick of a lamp, hence it produces a bad flame, and the wick gets clogged and charred, and it is not viscous enough for ordinary lubricating purposes.

Numerous varieties of lubricating oils, as well as vaseline paraffin wax, and other materials, are prepared from selected distillates of particular oils which lend themselves to special treatments. The vaseline is used in pharmacy, and the paraffin wax, after purification with charcoal and separation into qualities according to melting point, is largely used in the manufacture of candles, insulating materials, chewing gum, and waterproofing, etc.

Almost daily extended and often remarkable uses for petroleum products are found. The liberal use of oil on rough seas will often save a distressed ship from destruction by preventing the waves from breaking over the vessel; and the judicious application of certain oil products has been proved to very materially extend the life of macadamised roads, besides acting as an effective dust preventer. In tropical countries increasing use of petroleum is made to diminish the breeding of mosquitoes in swampy lands, a film of oil on the surface of water preventing the larvæ from breathing, by choking up their air passages.

Petroleum is used in the preparation of insecticides by emulsions with other chemicals. An important employment for certain residual products is the manufacture of waterproof compositions for treating felt, paper, or other substances which are sold as bitumen sheeting, etc. The dielectric properties of certain asphalts are applied in insulation materials, and the solvent properties of certain qualities of prepared distillates has led to their use as turpentine substitutes.

An important demand has arisen for pharmaceutical oils for internal consumption. They are colourless, tasteless, and odourless oils prepared from selected distillates of oils devoid of paraffin and sulphur, which are carefully distilled, refined, and decolorised by treatment with nitronaphthalene. These qualities of oil are also largely used as substitutes for salad oils.

One of the most remarkable and successful uses to which oil has recently been applied is the concentration of mineral ores, by which means the mineral contents of low grade ores can

be extracted from the gangue. The Elmore ore concentration process depends upon the mixture of well-crushed ore with an emulsion of oil and water by agitation in a vessel under a partial vacuum, when the well-known affinity of oil for metals leads to the particles of mineral matter becoming clothed with a film of oil, and rising to the surface of the liquid with the oil, whilst the unmineralised portion or gangue is precipitated.

Distillation of Petroleum.—The distillation and refining of petroleum can only be undertaken on a commercial scale after consultation with qualified chemical specialists, and the execution of many preliminary distillations of characteristic samples of the product to be treated. Only a brief outline of the usual methods adopted will be given, and readers needing information are referred to chemical works dealing with the subject, of which, however, there are very few. The engineering aspect has never yet been attempted.

Some high grade crude oils are simply exposed to heat from a steam coil, and "reduced" in open pans until the desired viscosity and freedom from moisture is reached to fulfil the duties for which the particular oil is being made, whilst a few natural oils are used direct in their crude state for lubricating purposes, after filtration to remove siliceous particles. Where crude petroleum is not employed direct for fuel or other purposes, it is subjected to a process of distillation whereby the various components of the oil are first expelled and then condensed, the condensates being grouped within certain ranges of density and flash point. The crude oil, sometimes previously warmed by waste heat, is introduced into steel cylindrical stills of varying design, heated by flues, and the expelled vapours are conducted from a dome above the still along pipes into a condenser. At first only light distillates pass over, but as the temperature of the still rises, denser distillates are expelled and are condensed. In the tail house leading from the condenser the condensed fluid discharges into a pipe from which there are a number of outlets, each controlled by a cock, and each leading to a separate storage

tank, so that an attendant stationed there is able to deflect the products to the requisite stock tanks as the distillation proceeds, and the density of the oil varies.

The above description sounds very simple, but there are many details which require consideration, and which may lead to considerable necessary modifications in the normal plant. Some oils foam badly, especially if contaminated with water, and unless special precautions are taken, much crude oil is carried over from the stills with the distillates. When the temperature of the still is over 300° C., and only the dense constituents of the crude remain, considerable decomposition of the oil will take place unless distillation is assisted with the aid of steam. Steam is now almost universally employed, and it is found that besides reducing the temperature of distillation and keeping the viscous fluid in a state of motion, it assists the removal of the heavy distillates, and carries them away from the still with less cracking. D. R. Stewart[1] thus ably describes the use of steam in distilling: "Water converted into steam expands seventeen hundred times. Our oil expands only one to two hundred times, and when distilled without steam, a great deal of oil has to be evaporated before the vapours mount to the exit pipe. Their specific heat and heat of vaporisation are not great, and they readily condense on the top of the still and fall back, and are redistilled with some decomposition." Steam is admitted by a perforated pipe which extends the full length of the still base, and when the temperature of distillation is high, as in the production of lubricating oils, it is superheated to a temperature in excess of that of the oil before admission.

If products heavier than solar oils are to be distilled, it is unusual to carry out a complete distillation down to the lubricating oils in the same still, owing to the high temperature needed, but the residuum of the illuminating oil stills is transferred to others of special design for the extraction of the lubricating oils, when, in addition to steam, a partial vacuum is also main-

[1] "The Oil Shales of the Lothians."

tained in the stills to diminish the temperature of distillation, and avoid decomposition and burning.

The process of "cracking" is also made much use of in modern refineries, whereby a larger proportion of lighter products is obtained than would otherwise be the case. Cracking is brought about by raising the temperature of the oil in the still above the normal height for the distillate being collected, and leaving the upper exterior surface of the still exposed to the atmosphere, so that part of the products of distillation are thereby condensed and caused to fall back into the hot fluid. The result of the action is the reduction of hydrocarbons into products of lighter density and lower boiling point, accompanied, however, by the formation of a certain amount of permanent gas. The exact action of "cracking" seems little understood, and certainly "cracked" oils are inferior to uncracked, and they require more refining.

Increasing demand for petroleum spirits for use in internal combustion engines has acted as an incentive to inventors of cracking processes, especially as the price of suitable products has risen to a very high figure. Cracking processes mainly rely upon distillation under pressure or passage of vapours over hot surfaces in the presence of a catalyser, whereby heavy hydrocarbons are broken up into those of less complexity of the cyclic order. Solar oils and kerosene may be mainly converted into products with a boiling point suitable for internal combustion engines, but they need refining to remove objectionable odour and discoloration, and are often mixed with a proportion of light direct-distilled spirit to ensure quick ignition.

Distillation on a continuous principle has long been conducted in Russia, and since 1900 the process has been widely extended to other countries with highly beneficial results. For continuous distillation the stills are placed in batteries, each still being mounted slightly lower than the preceding one, so that oil admitted to the upper can flow by gravitation through the whole series, the rate of flow being regulated by cocks between each still. This pretty process is thus well described in the "Encyclopædia Britannica": "In the continuous process of distillation, instead of a single

still with a progressive temperature, there is a series of retorts heated to successively higher temperatures which are carefully maintained, and the crude oil is caused to flow slowly and continuously through the whole series, being thus subjected to a steadily increasing heat, whilst the contents of each still remain practically constant. In this manner each still yields continuously a product of given volatility, corresponding to the temperature at which it is maintained, and from the series of stills a range of products is continuously obtained, corresponding to that yielded by the intermittent system within the same limits of temperature."

Modern stills are usually of the internal corrugated flue type, first introduced with great success in Austrian refineries. Considering the fuel economy resulting from this design, it is remarkable with what hesitation they are being adopted outside the Continent of Europe. Quite recently an apparatus known as a petroleum circulator has been invented for creating a rapid circulation in stills, and it is anticipated that considerable saving in fuel and a greatly increased still capacity will result from its employment.

Fig. 44 illustrates the lay-out of a modern petroleum distilling plant in which are incorporated two features of special interest, namely, dephlegmators on the early stills, and a system of pre-heating the crude by utilisation of a portion of the contained heat of both residuum and distillates.

Dephlegmators consist of vessels placed above the stills through which the vapours pass on their way to the condensers. The vertical vessels contain a series of baffles which check the flow of fluids, and condense heavier particles mechanically carried from the stills, whilst the ascending vapours re-evaporate any light condensates. A very perfect separation of products is thus obtained, greatly simplifying all subsequent refining processes. The rate of distillation affects in a striking way the percentage and quality of distillates obtainable from any particular crude oil.

Lubricating oils and solid paraffins are usually extracted from the residuum of primary distillation from which benzines and lamp oils have been withdrawn. Solid paraffins are often carried over with illuminating oil distillates, and some of the lower quality

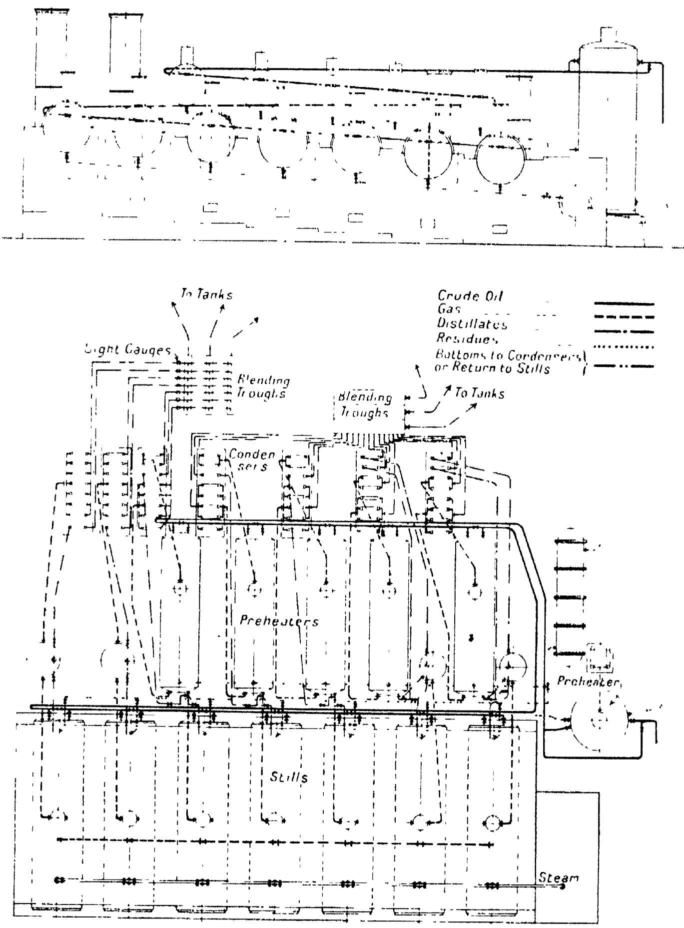

FIG. 44.—DIAGRAMMATIC SKETCH OF MODERN PETROLEUM DISTILLERY (GROELING SYSTEM).

Stills, internal corrugated flue type, on continuous principle.
Preheaters using both heat of residues and latent heat of distillates.
Condensers of radiator pattern.
Dephlegmators attached to two first stills.

Burma lamp oils prepared for the Indian market are usually solid at 60° F. They, the paraffins, however, concentrate mainly in the residuum from a certain point ascertained experimentally, and from thence onwards it is usual to distil under reduced pressure, and in the presence of superheated steam to minimise decomposition. Residues containing paraffin wax are naturally valueless for lubricants, and from such oils it is only certain paraffin-freed oils that can be converted into lubricants. When solid paraffins are absent, the residues yield under careful distillation, in partial vacuum, viscous products that, after refining, possess varying lubricating properties. This process was formerly conducted in circular cast-iron pot stills, but in modern refineries cylindrical stills on the continuous principle are being adopted.

Refining.—Most petroleum distillates require some process of purification before they can be placed on the market for domestic or commercial purposes. Illuminating oils, in particular, when unrefined, yield a smoky flame, and contained resinous matter clogs the wicks of lamps and hinders combustion. Small quantities of sulphur compounds also frequently exist that produce objectionable odours when the oil is burnt. The smoky flame is usually attributable to the presence of higher homologues of the unsaturated hydrocarbons, often mechanically carried over during the process of distillation, and frequently removed or much reduced in quantity by a second distillation.

Refining is almost universally accomplished with the aid of sulphuric acid, followed by a treatment with caustic soda. The action of sulphuric acid is not entirely understood, but the unsaturated and undesirable hydrocarbons are attacked by the acid, with the formation of a tar which is precipitated together with unaffected acid and can be drawn off as "sludge." Agitation with soda after a preliminary washing with water produces a certain amount of purification, but its main purpose is to neutralise acidity and remove acid products. Other oxidising agents, like permanganate of potash and ozone, cause some reaction, but sulphuric acid has rarely been improved upon in practice.

The distillates are agitated in cylindrical iron vessels with compressed air, or with mechanically-worked paddles, the latter,

especially in the more improved types that ensure intimate admixture, becoming increasingly popular on account of the deteriorating effect of moist air on the acid. Formerly lead-lined vessels were common, but if pure acid and no moist air is used steel agitators do not suffer excessive corrosion, and last a long time. During treatment the oil decreases in density in consequence of abstraction of dense hydrocarbons, but, in warm climates especially, the agitation itself causes evolution and loss of volatile products, and so counteracts the reverse effect of the acid treatment. The effect of refining on the flash point of a distillate is variable, some distillates, usually the lighter, having it raised, others lowered by the operation.

Carefully conducted slow distillation of some oils will yield products that can be used direct without refining, but even benzines are usually given a light treatment with acid and soda, and are re-distilled with steam. Some crude oils yield products that are only marketable when re-distilled after a preliminary refining, and occasionally satisfactory results can be achieved by a primary treatment of the crude with sulphuric acid and soda before any distillation.

It is estimated that only about 3 per cent. of the sulphuric acid added to the distillate is actually used, and that the remaining 97 per cent. is necessary to secure contact of all the distillates with acid during agitation. Some 5-10 per cent. of heavy hydrocarbons are usually abstracted from the distillates by the acid, and these can be recovered by settlement, washing, and treatment with waste alkali, and can then be used as fuel. In shale oil works waste sulphuric acid is used for treating ammonia water for the production of sulphate of ammonia.

Baku refineries in South Russia use 0.75 per cent. of H_2SO_4 and 0.25 per cent. of NaHO for refining their kerosene under the worst winter conditions: Pennsylvanian refineries use 4-10 lbs. of H_2SO_4 and 1 lb. of NaHO per barrel of illuminating oil: and in Roumania an average of about 0.5 and 0.10 per cent. of H_2SO_4 and NaHO respectively is used.

One recent process of refining calls for especial reference, namely, the Edeleanau, in which liquid sulphur dioxide (SO_2) is

the purifying agent. Early mechanical difficulties that obstructed its practical employment have been overcome, and it is believed that an immense future lies before this clever invention.

Liquefied SO_2 is added to the distillate in a closed vessel with a glass side, where the operation can be observed. A dark cloud of hydrocarbons immediately forms, and at once settles with the SO_2 to the bottom, from whence it is allowed to discharge into a vessel, the purified distillate passing into another vessel. The temperature, often as low as $-10°$ C., and pressure at which the operation is conducted, depend on the character of the oil, naphthenes being dissolved at a much higher temperature than aromatic hydrocarbons. Under atmospheric pressure or a slight reduction of pressure and increase of temperature, the SO_2 is evolved, abstracted by a compressor, and recompressed into liquid for reuse. One precaution is essential to success, the distillates must be entirely freed from water, otherwise sulphuric acid is formed with disastrous consequences to the plant, therefore they are first passed through calcium chloride filters to remove the last traces of water.

Sulphur dioxide owes its efficacy largely to its violent attack on the heavier cyclic unsaturated and especially aromatic hydrocarbons, which are often the cause of the poor burning properties of lamp oils, but it also removes or reduces the quantity of sulphur compounds in a surprising way, producing good illuminants from oils that are usually in little request. The aromatic hydrocarbons abstracted are valuable for the production of turpentine substitutes, etc.

Some crude oils, like those of Ohio, Lima, Indiana, Texas, Mexico, Canada, Persia, Egypt, contain such persistent and obnoxious sulphur compounds that it is necessary to treat distillates prepared for domestic purposes with copper oxide or litharge (PbO) to secure their removal. These chemicals are recoverable for reuse by burning off the sulphur that has combined to form CuS or PbS.

Mineral earths have been used to some extent for refining oils. Distillates are agitated with fuller's earth or with bauxite, to the particles of which some of the heavier and discoloured

hydrocarbons adhere, and are precipitated or filtered out. These mineral earths are recovered and revivified for repeated use by heating to a high temperature, and pulverising

Paraffin wax is extracted from the distillates in which it exists by a reduction of temperature and forcing through a filter press. The crude scale is scraped from the canvas filters of the press, subjected to high hydraulic pressure in canvas bags to remove as much oil as possible, and then undergoes a process of sweating and washing with acid and soda and treatment with charcoal. The so-called blue oil obtained from the filter presses at low temperature is valuable for the manufacture of low-setting lubricants.

Sweating is usually conducted in open pans, where the melted wax is run over a layer of water. On removing the water, the solidified cakes rest upon a gauze frame, so that when the chamber in which they are placed is heated by steam the contained oil and low melting point wax sweats out, leaving only that portion with a melting point higher than that of the chamber. By repeating the operation and treating the scale with sulphuric acid and soda any degree of refinement or melting point can be obtained within the limits of the oil contents. Paraffin scale is often whitened by agitation in a melted state with prussiate charcoal.

The old process described above is now being replaced by the vertical type of sweating stove in which the crude scale is deposited in the annular space between vertical cylinders lined on both opposed surfaces with gauze, through which the oil and low melting point fractions issue as the temperature of the chamber is regulated. Temperatures are adjusted with great nicety by steam valves and a fan, enabling the wax to be fractionated, cooled, and heated in the briefest period of time.

CHAPTER VII.

SYSTEMS OF DRILLING OR BORING FOR PETROLEUM.

Drilling or Boring for Petroleum and Natural Gas—Selection of Drilling Plant—Boring Records—Cable Drilling—Wire Cable Drilling—Circulating Cable System—Rope Sockets—Tool Joints and Tightening Apparatus—Percussion Bits—Eccentric Bits—Under-reamers—Handling and Dressing Bits—Appliances for Removing Debris—Canadian System of Drilling—Russian Freefall System—Rotary Flush Drills—Fauck "Rapid" System—Fishing Operations and Appliances—Portable Drills—Cost of Drilling—Suppression of Wild Oil and Gas Sources—Shooting or Torpedoing Wells—Contract Drilling.

Drilling or Boring for Petroleum and Natural Gas.—The selection of a site for trial drilling in a new territory is decided by circumstances discussed on p. 219, and in Chapter III. is given a description of representative examples of the strata that may be encountered.

Unproductive seams of porous strata are interspersed amidst petroleum-yielding beds in an oil series, and in some cases considerable discretion is needed to decide when an oil-bearing stratum has been penetrated. This difficulty is particularly pronounced when water infiltrates into the well and obstructs the entry of any petroleum which might otherwise exude into the well, and also obscures the identity of the sand by washing away the contained oil.

Naturally, a definite test can always be made by giving the well a trial bailing with the bailer if there are misgivings concerning the worth of the indications, but this course is always delayed as long as possible in most formations, as the strata become disturbed by the removal of the liquid, and the walls of the well may collapse ("cave") and uncompact beds be set in motion by withdrawal of sand. The less material removed from the well during drilling, and the less the strata are disturbed by bailing, the further will each column of casing be carried,

and incautious attention to such details may lead to the enforced reduction in size of casing until the limit of practicable diminution is reached long before the required depth is attained.

Usually an escape of gas and a steady accumulation of oil in the well will indicate the proximity of an oil source, but drilling should only be suspended for a trial bailing or pumping after continuing some distance into an oil-bearing bed. A yellow emulsion is often the first indication of oil in a well with a high water level, the colour deepening, and being gradually followed by a separation of oil and its accumulation on the surface of the liquid. In several cases the author has personally given instructions for a trial bailing to be made when there was only water in the well and no indication of petroleum, being guided solely by the character of the sands raised and the knowledge that an oil-bearing horizon had been reached. In one such example, where water only was bailed for a week before being overcome, as much as 150 tons (1,125 barrels) of oil daily were obtained, and in another instance where water which filled the well was subsequently excluded by a cementation, a production of 500 tons (3,850 barrels) daily was obtained for a while, and in two years the well yielded 140,000 tons (1,050,000 barrels.) of oil, although no indications of petroleum had been observed during drilling.

The rate of drilling varies greatly. In oil-fields where the strata do not "cave" and the wells are of small diameters, the average rate of drilling may reach 50-150 ft. daily with a cable rig, but where the strata are much disturbed or steeply inclined, and "caving" is constant, the rate often may not exceed 6-10 ft. daily. No definite relationship between speed and diameter can be predicted, nor do depth and speed bear any definite ratio to one another, but within the limits of an oil-field ratios can be established by plotting results.

Where the strata are compact and several oil sources of limited capacity have been passed, it is a common practice to insert the last column of casing with perforations at the depths where the oil shows occurred, the outer larger casings used for temporarily excluding the oil being then removed to permit these

sources to supplement the main supply, if not required for the exclusion of water. Indications of petroleum during drilling are often described as "*oil shows*," and productive beds as "*pay streaks*."

Only rarely is a class of strata encountered that defeats the persistence and ingenuity of the engineer. In the absence of supplementary plant, operations may be temporarily or indefinitely suspended, or the cost of suitable materials may not be justified by events, but unqualified defeat is rare. One of the most rebellious substances to come upon in drilling is asphalt of a certain consistency that oozes from fissured clays, and creates a sticky mass through which any object can only with the greatest difficulty be moved. By attaching itself to the drill stem and tools, their motion is arrested and their recovery is seriously jeopardised: only constant, patiently administered pulls for long periods will effect their abstraction. Similarly the same substance, or something closely allied to it, will run into a well and form a base upon which the drill rebounds as from a rubber disc. Hours of steady pounding may fail to destroy the cohesion of such a substance which declines to mix with foreign matter.

Persistent drilling for days may destroy or dispel a small mass of such substances, but if they continue to ooze into the well it is only possible to continue drilling by excluding the source with casing slowly pressed past the troublesome zone. Admixture with benzine or other solvents after extraction of water might aid progress under some circumstances.

Clays of a certain consistency and plasticity resist the formation of a puddle or mud, but instead tend to squeeze up around the bit, forming a solid mass in the less confined space around the stem. Such result makes it necessary to drill upwards with the jars to secure the release of the bit. This quality of the strata can be neutralised by the occasional insertion of sand whilst drilling is cautiously prosecuted. Drilling in certain sands can likewise be aided by the addition of clay, the latter apparently hindering the rapid settlement of agitated sands such as is especially noticeable in highly saline waters.

Attention has recently been drawn by Dr W. Petrascheck[1] to

[1] "Aids to Deep Boring in Clay."

the causes and means of reducing caving and swelling that are very prevalent in bore holes.

When, as frequently happens in a deep earth-boring, a clay or marl deposit is met with, difficulties of a more or less serious nature may delay the progress of the work. The clay swells and fills the boring, jamming the bit or the rods, or, in the case of marl, the sides of the hole crumble and fall in, with similar results. This tendency to swell or crumble is greatly increased when water is present. A lump of dry clay or marl when placed in water usually loses its form. But water is commonly used in boring to clear the hole. This water, consequently, may be the cause of much trouble in boring through a soft argillaceous bed. All clays contain a colloidal substance to which they owe their plasticity, and it is to the solvent action of the water on this colloid that the disintegration of the mass is due. It has been found that an aqueous solution of certain salts, such as chloride of magnesium, chloride of calcium, chloride of sodium, sulphate of sodium or magnesium, etc., has a coagulating effect on the colloidal substance in the clay, so that disintegration does not follow immersion in these solutions. Therefore a concentrated solution of one of these substances, all of which are very cheap, may be used as the clearing water in the bore hole. Recent experience shows that when such a solution is used, a clay or marl bed may be bored through without hindrance from swelling or crumbling, and without the subsequent necessity to line with iron pipe that portion of the bore hole, for in dry ground the sides remain sufficiently stable. Milk of lime, or any alkaline solution, dissolves the colloid and disintegrates the clay more rapidly than pure water. These substances, therefore, are unsuitable for the purpose in question.

When drilling through rock salt and beds impregnated with salt, as the Saliferous Miocenes of Roumania, saturated solutions of salt are an undoubted benefit in preventing dissolution of and extraction of salt from sedimentary beds.

Although loose flowing sands no longer dismay the operator, there are certain severely fractured, unconsolidated clay shales that disintegrate and cave immediately they are disturbed, and

yield a heaving mass that not even mud pressure will restrain. One especially difficult case that came under the author's notice was complicated by the presence of films of oil and small pockets

STRINGS OF TOOLS.

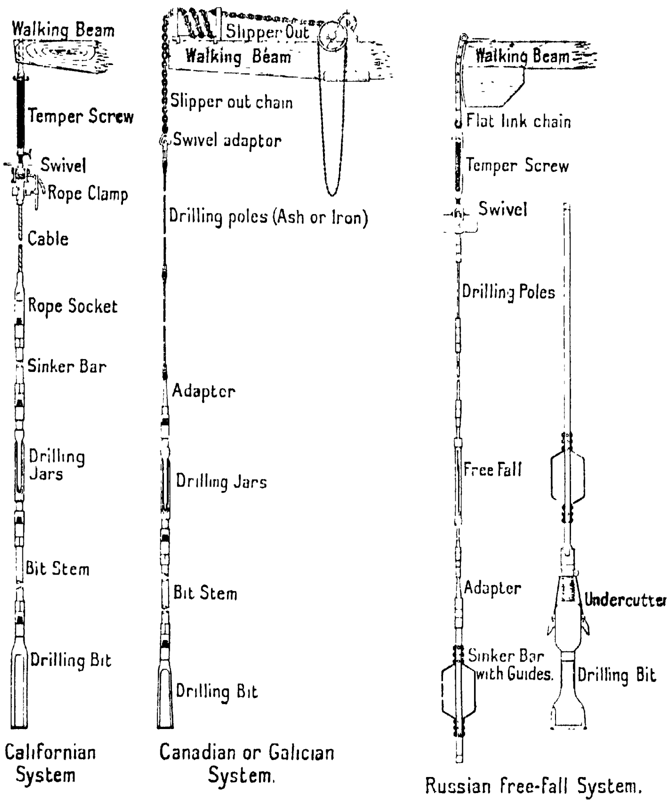

Fig. 44A.—Strings of Percussion Drilling Tools showing Feeding Attachments.

of gas in the innumerable slip planes of a steeply inclined, thick deposit of clay-shales. The insertion of casing at frequent intervals affords some measure of relief under such circumstances, but its manipulation is difficult, and the removal of hundreds of tons of disintegrated strata leaves the columns without adequate

support, and consequently very susceptible to fracture through lateral movements.

Each case must be considered individually, and the merits and objections of various systems must be discussed. Usually dry drilling though slow will give the best results in such loose strata, a rotary being brought to a standstill after perforating several hundred feet in a few hours.

Oil-well drilling is almost universally performed without interruption, day and night, in two working shifts or "tours" of twelve hours each. The selected time is usually midday to midnight, thus giving to each attendant some part of the day. This practice has been forced upon operators by the dangers and delays arising from intermittent work, hours having often to be spent in recovering the position of the previous day, after settlement of sediment, and perhaps seizure of casing.

Selection of Drilling Plants.—Drilling machinery is selected to suit the strata it is designed to attack, and may be roughly classified as under:

Hard strata - - -	Heavy percussion. Core drills (diamond or chilled shot crowns).
Soft caving clays and loose sand - - -	Rotary, hydraulic drills. Percussion drills with circulating attachment.
Mixed strata - -	Combination drills.

The drilling systems in use may be classified as under:—

Percussion drills -	Pole tool system - -	Canadian ash pole system. Galician iron rod system. Freefall system.
	Cable systems - -	Manilla cable. Steel wire cable.
Hydraulic percussion - - - - - -		Fauck "rapid" system. Circulating cable system.
Attrition (hydraulic) systems - -	Core drill and those with circular cutters -	Diamond drills. Chilled shot drills. Tooth cutter drills.
	Disintegrating drills -	All rotary drills with flat, chisel, cone, or disc bits.

Fig. 44A illustrates, for comparison, three strings of percussion drilling tools described subsequently in more detail.

The choice of a drilling system for prospecting in a new

district depends not only on the lithological character of the strata, but upon the physical conditions that prevail. Prevalence or scarcity of water, facilities of transport, character of available fuel, all bearing on the problem of power, are reflected in the rig. The non-existence of a suitable reversing clutch practically precludes the use of a combination of internal combustion engine and systems calling for reverse movements. Scarcity of water restricts the use of hydraulic processes, and absence of good water is a hindrance to the employment of steam without subsidiary condensing appliances or purifying processes.

A prevalence of hard, compact rocks can be negotiated successfully with a cable rig, but strata containing frequent recurrences of hard bands between non-caving softer strata can better be attacked by a Canadian rig, which permits the attachment and positive application of under-reamers that enlarge the hole to allow the descent of casing without frequent reduction of diameter. Although the speed of pole tools does not reach that of other systems in easy ground, they afford a means of penetrating almost all kinds of strata, and allow a wider range and combination of instruments and movements than any other system, whilst not precluding the use of a cable at will.

Soft, caving Tertiary strata and thick deposits of loose flowing sands can best be overcome by the modern hydraulic processes in which mud mixtures are employed. Their use was, till recently, restricted, through the absence of tools that would effectively pierce hard layers interspersed amidst the softer material, but recent inventions have removed this obstacle. Hydraulic processes are not favoured for prospecting, as they afford such little evidence of the nature of the strata being penetrated, and conceal indications of oil, but in proved fields, where depths are approximately known, the wet method of drilling may be changed over to the dry at any desired point. Unfortunately, drills that aim at the extraction of a core by the use of an annular cutter have found little favour with oil-field operators. Such processes impose restrictions that are unpopular, although in hard strata excellent cores can be cut and extracted by using diamond crowns, steel-cutting heads, or chilled shot.

Notwithstanding the disadvantage of hydraulic plants they are steadily intruding into new fields, and operators are submitting to the dearth of geological data in face of advantages of speed and simplicity of working. Intelligent observations recorded by a conscientious and experienced driller will yield certain data, although recognition of specific beds of no great thickness is impossible. Speed records are even more useful than debris examinations, as they bear a direct relationship to the hardness of the material being drilled, provided due allowance is made for sharpness of drill. Particles of rock may reach the surface long after a hard bed has been passed, but still afford some data, if meagre, of the formations being passed.

Sandstones, limestones, and hard rock salt can best be pulverised by heavy cable tools. Pole tool systems are a source of constant trouble in such ground owing to repeated breaking of the rods as a result of the excessive vibration they sustain. Specially large joints should be specified for the tools, to diminish the danger of fractured pins.

Combination rigs are now being more largely used, thereby providing for contingencies that may or may not arise. The two selected systems are often placed at right angles in the same derrick, thus providing means of at once changing from one system to another in the event of a change of strata.

The development of an oil-field invariably leads to modifications of some recognised system whereby the local peculiarities can be best overcome. Russia, Galicia, Texas, Louisiana, and California all provide instructive lessons in the production of plant and systems adapted to the peculiar local conditions. Observers of limited experience are inclined to indulge in criticisms of methods not corresponding with conventional ideas at home, when visiting new fields; quite ignoring the totally different features they present.

In this connection, the utility of portable drills for oil prospecting should not be overlooked, as their portability and lightness assign to them no mean value for exploring to depths of 700-1,000 ft. In several fields with which the author

is professionally associated, they have competed in speed with all other varieties of drills, and been retained for the eventual development of shallow fields. A third drum should be prescribed for manipulation of the casing line without the necessity of disengaging the drilling cable. Either a derrick or shear legs stayed by guy ropes should then be erected to support the casing blocks and sustain the weight of the column of casing.

Boring Records.—Whether prospecting in a new oil-field or exploiting an old one, complete, and as nearly as possible accurate, records of the borings should be kept. In some countries legislation enforces the compilation of drilling returns for official reference, but whether this is compulsory or not daily journals of all boring wells should be preserved. The geological information afforded by the early borings in a new district is of immense importance in deciding upon the direction in which future operations shall extend, and not only should the geological data be compiled, but a full history of the drilling should be given, in order that subsequent operators who have not had the early experience may realise the difficulties encountered in passing through the different beds.

A full boring journal should be divided into a drilling and a geological section. In the former should be stated the time worked, number of feet drilled, the length, duration, and cause of any delays or stoppages, and any special remark which would indicate the cause of slow drilling or loss or breakage of tools. Full particulars should also be given concerning the size, thickness, and kind of casing or lining tubes inserted or withdrawn, and notes should be made as to its freedom or tightness. In the geological return the depth should be given at which every change of stratum occurs, and as full a description of each stratum as possible; any observed change of level of liquid in the well should be recorded, and the presence and character of water, petroleum, or gas should be fully reported.

The importance of correct data can only be appreciated by those closely allied with oil-field development, as in cases where unexcluded surface water fills the well, an appearance of certain kinds of sand or the escape of a little gas is sufficient

to indicate the possible presence of an oil source and decide a definite course of action.

In compiling boring journals of percussion drilled wells the following hints may prove useful. Clays should be prefixed by their colour or shade in a hydrous condition as raised from the well. If of a particularly stiff constitution they should be so described, and if they "cave" a great deal and show a flaky structure they can be described as clay-shales. A mixture of clay and sand in which the former predominates should be described as sandy clay or sandy shale if there is no reasonable cause to believe the sand is from an upper source or in separate laminæ.

Sand and sandstones can generally be distinguished by the vibration caused by the blow during drilling, and by particles of the rock which are almost invariably raised with the sludge when it is the latter. The colour should be noted, and they should be differentiated by the fineness or coarseness of the grains, or described respectively as grits, gravels, or conglomerates if the particles are sharp, rounded, or cemented together respectively. If much lime is present a sandstone should be described as calcareous, or if impregnated with iron a stratum should be termed ferruginous.

Sands should be classified as "*water*," "*running*" or "*quick*" *sands* if they contain water (the latter term being confined to those which rise in the casing and fill up the well as fast as removed), as "*gas*" *sands* if they contain gas but no oil, and as "*oil*" *or* "*bituminous*" *sands* if they contain petroleum, or solid or semi-solid petroleum-like products.

Limestones or marls are generally recognised by the colour of the sludge, but can always be definitely distinguished by the addition of a little dilute hydrochloric acid, when a brisk effervescence ensues, and the material dissolves with evolution of carbon dioxide.

On the following page is shown a Boring Return used by a number of companies with which the author is professionally associated. The form was prepared to cover general prospecting and development, and has been found sufficiently complete for

most purposes, although in some fields where exceptional conditions exist a modified return is sometimes used. The drillers send in a single form each day, and the information is then

BORING RETURNS.

Commenced.......................... *Completed*.................... ...

Well No...............

Section or Plot No...............

Date.	Amount bored	Total Depth of Boring	REMARKS. *N.B.*—State here the cause and duration of any delays or stoppages, and give full particulars of any auxiliary work such as fishing for lost tools, repairing casing, cementing, trial bailing &c.	Casing.			
				Lowered.		Removed.	
				Size, Thickness, and Quantity	Total Depth of Casing	Size, Thickness, and Quantity.	Total Amount Removed.

Signature of Manager...............................

Date...............................

GEOLOGICAL REPORT.

Description of Strata.	Depth at which Stratum was Penetrated.	Level and Nature of Liquid in Well.	Specific Gravity of Oil, or Salinity of Water in Well.	REMARKS. *N.B.*—State here any peculiarities which may manifest themselves. Indicate hardness or caving character of strata and presence of gas, water, or oil. Any change in level or character of liquid in well should be notified in Column 3, and more fully described here.

Signature of Manager...............................

Date...............................

transcribed into a foolscap size book of printed forms kept for the purpose in the office. When companies send home drilling returns from abroad, it is usual to have forms of sufficient size to show either seven, fifteen, or thirty-one days' work according

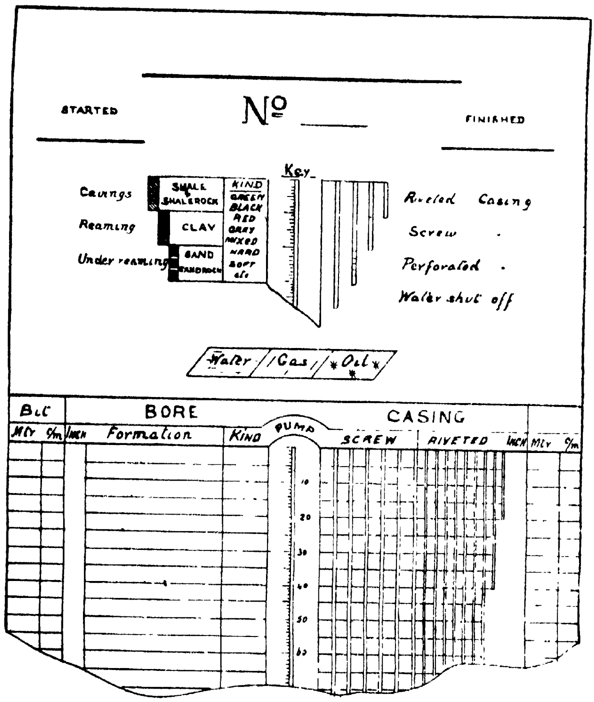

Fig. 45.—Form of Boring Return used in Galicia.

to the frequency with which the mails leave or the returns are required.

Fig. 45 illustrates a form of boring return, designed by Geo. von Kaufmann, and largely used in Galicia by the oil producers.

The United States Geological Survey issued some very excellent instructions for the preparation of well records in the "Record of Deep Well Boring for 1904," which should be read by those interested in the question.

COMMENCED 23RD JULY 1912.

Rig in use..

Contractor ....

At 550 ft. water rose to within 30 ft. of surface.

Much gas at 800 ft., and 20-in. casing got damaged and had to be repaired.

Trial bailed at 1,300 ft., but quantity of oil small. Sp. gr. .885 : gas fairly strong and sweet.

Much trouble freeing casing afterwards.

At 1,450 ft. salt water rose to within 450 ft. of surface. Some gas present.

Thick oil sand at 1,700 ft., but no great indications of oil. Decided to deepen without trial bailing.

At 2,100 ft. rich oil sand struck; sand rushed up casing, and well flowed at intervals of a few hours.

Yield about 135 tons daily.

Drilled in 270 days; average 8 ft. daily.

Average per drilling day, $\frac{2140}{204} = 10.4$ ft.

" working day, $\frac{2140}{234} = 9.14$ ft.

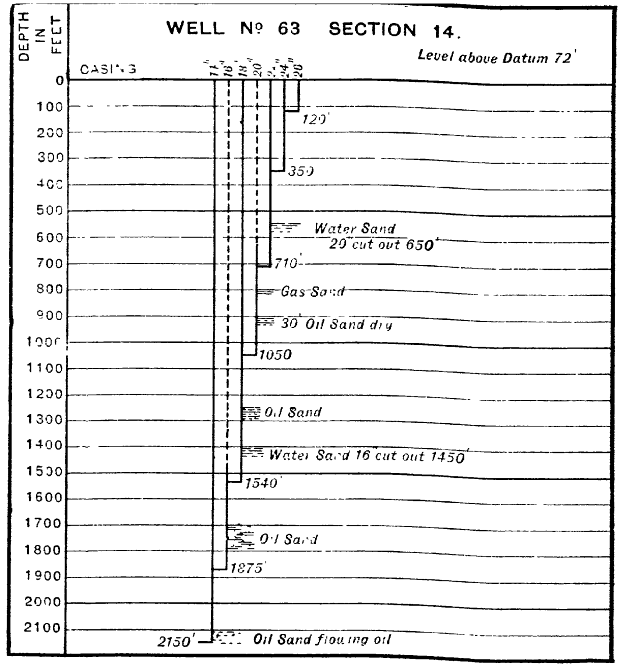

Fig. 46.—Useful Method of keeping Field Note-Book.

Books should be in squared paper, and two opposite pages allocated to each well. On one side are noted important details, and on the other a diagram of the well is shown.

A useful way of preserving records of wells in a note book for field use, enabling data to be added as the work progresses, is shown in Fig. 46, based on a page from one of the author's field note-books. Clays, sands, and oil sands, or other specially interesting or distinctive horizons, should be tinted with coloured pencils, thus indicating at a glance the main features. Abstracted casing can be shown by dotting the portion removed. If the well mouth levels are taken and allowed for in each section the comparison of any two pages shows the vertical relationship of the various strata.

Cable Drilling.—By far the most popular and widely adopted method of drilling for oil and gas in recent years has been the cable system, which relies upon the energy stored in a string of heavy tools on a stretched rope. It is unusual to sink a shaft wherein to manipulate casing except where casing difficulties are anticipated.

A timber derrick from 60-100 ft. high, with a 16-20 ft. base, is mounted on a heavy framing. On one side is erected the "*rig*," which imparts the various desired movements to the tools and accessories of the process. The main drive is received from the engine by a wooden band wheel from 8-12 ft. in diameter keyed to a shaft, upon which, at one extremity, is also attached a crank that transmits, through the medium of a connecting rod, an oscillating movement to an overhead pivoted walking beam. Several holes bored in the crank enable the pin to be placed at varying radii from the centre, thus admitting an adjustment of the stroke to the walking beam to suit requirements.

From the free end of the walking beam that just overlies the mouth of the well, when horizontal, is slung a "*temper screw*" and "*rope clamp*," to which the cable can be attached when the tools are lowered into the well. The tools are suspended from a cable which is coiled on a bull wheel shaft on the side of the derrick opposite to the rig, and it is driven by a chain or crossed drive-ropes leading from a sprocket or grooved tug wheel on the side of the band wheel to a corresponding bull wheel 7-8 ft. diameter on the extremity of the bull wheel shaft.

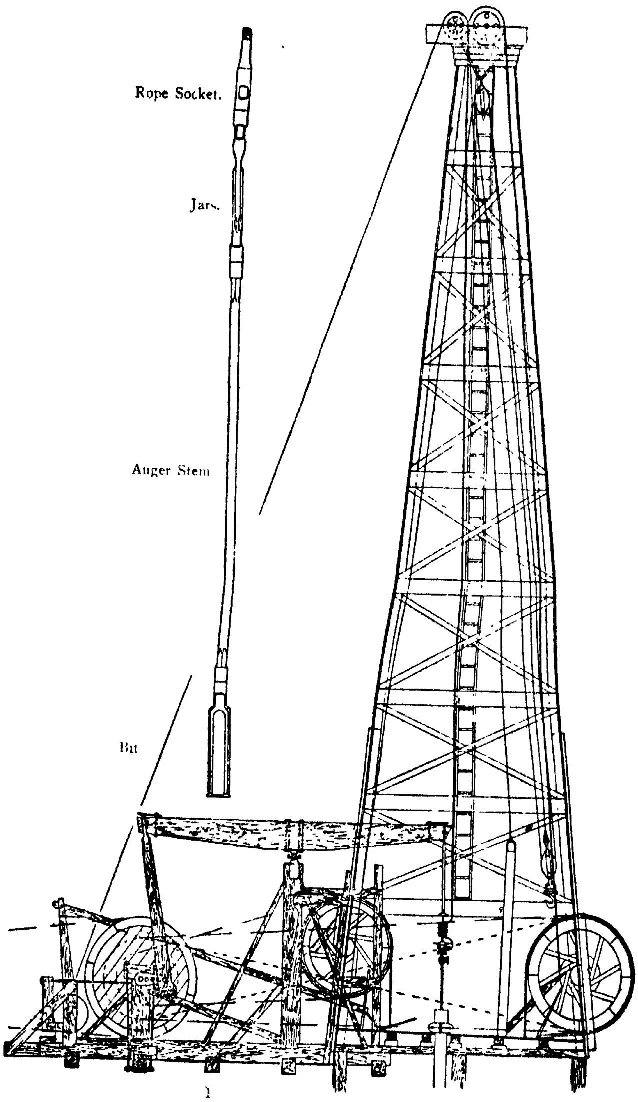

Fig. 47.—Californian Type Cable Rig.
Showing string of tools at side. The driving ropes are always crossed in practice.

Mounted immediately behind the band wheel is a drum, known as the "*sand reel*," on the shaft of which is fitted a small pulley that can be drawn against the face of the revolving band wheel by levers, thus causing its rapid rotation when so thrown into operation. Upon this reel is coiled the "*sand line*" which carries the bailer, its speed of descent under the influence of gravity being moderated by forcing the lever backwards, and bringing the friction pulley in contact with a stationary wooden block. As this pulley becomes very hot in deep wells, through slip in driving and friction in controlled descent, modern reels are often furnished with two pulleys, one of which comes into operation for raising, the other only for restraining the rate of descent, thus allowing each to cool off alternately. Sand reels are likewise designed with a separating disc that enables the wire line to be separated into two portions: that which is needed for the attained depth of well, and is consequently repeatedly uncoiled and wound up, and that in reserve, thus protecting the rope not immediately required, and diminishing unequal winding on the drum.

What is known as a "*calf wheel*" is sometimes added for manipulating a line from the casing blocks, otherwise it is necessary to disconnect the drilling cable from the bull wheel shaft and use this for the purpose. A calf wheel and shaft are mounted on the rig side of the framing and operated by a chain or ropes from a grooved or sprocket pulley on the end of the band wheel shaft.

At the summit of the derrick are placed the grooved pulleys, over which pass respectively the drilling cable, sand line, and casing line. Steel crown blocks with pulleys affixed are now procurable, wherein good lubrication is assured, and consequently smooth running. Cable drilling as designed above necessitates the use of a reversing engine, to which must be fixed a suitable gear that enables the operator, by means of a rope or rod, to have full control over the engine from the derrick both as regards speed and reversing arrangements.

A full string of cable tools is some 40 ft. long, and consists of bit or drill, auger stem, jars, sinker, and rope socket, all described hereafter. After attachment to the rope they are

suspended in the derrick and lowered into the well, a band brake on one side of the bull wheel shaft being applied to arrest the speed of descent to a safe amount. When the tools are near the bottom, the temper screw is attached to the cable, the weight thereby being thrown on to the walking beam, and the bull wheel shaft being released. A few feet of cable are uncoiled from the bull wheel shaft, and the engine then started, and speeded up till the oscillations synchronise with the natural vibrations of the rope. By feeding out the temper screw, the bit is lowered until a blow is delivered, and then periodically fed out as the material is pulverised and the bit fails to strike an effective blow.

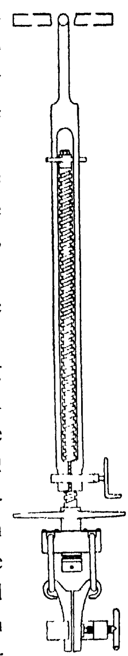

Fig. 48. Temper Screw.

As soon as the bit shows signs of not falling freely, the slack rope is taken up on the bull wheel shaft by attaching the driving ropes or throwing the chain into gear, and the temper screw thus relieved of weight, the connecting rod or "*pitman*" is disconnected from the crank-pin, and the beam then allowed to recline in an inclined position out of the way whilst the tools are raised to the surface and placed at one side of the derrick. The bailer is then lowered and the well cleaned out, sufficient water being run into the well previously to promote the formation of a mud capable of recovery by bailers.

Obviously, drilling from the beam could not be started with a 40-ft. string of tools, consequently the first hundred feet or more are drilled by a process known as "*spudding*." For this operation the beam is disconnected from the crank-pin, and a grooved collar slipped on in its place. By means of a spudding shoe connected by a rope to the roller, a grip is taken of the drilling cable near the bull wheel shaft. By jambing the brake on the bull wheel shaft, and putting the main shaft in motion, the horizontal motion imparted to the connecting rope transmits to the cable from which the tools are suspended a vertical and reciprocating movement. Periodical release of the brake feeds

the tools downwards as spudding proceeds, the spudding shoe adapting itself to new positions as work progresses (see Fig. 49).

Casing is inserted, abstracted, or manipulated to retain the freedom of the column by pulley blocks operated from the calf wheel already alluded to. In the latest American rigs the use of two blocks has been discarded in favour of a series of pulleys arranged on the crown block, through which the block line can be threaded after each turn over the suspended travelling block. Equalisation of weight on the derrick is better attained in this way, and the removal of one swinging block gives increased working height in the derrick.

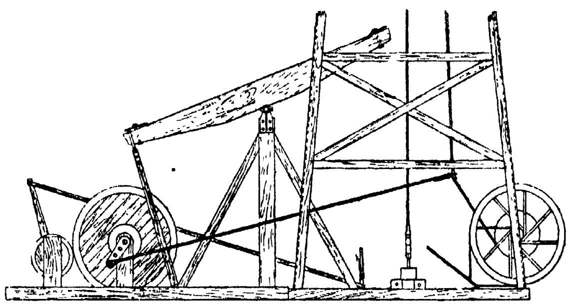

Fig. 49.—Method of Spudding and Driving Casing.

When driving casing, drive clamps are bolted to the stem below the joint with the rope socket.

Considerable judgment is needed to secure the full capacity of a cable rig. The speed of drilling must be carefully regulated to suit depth of well, nature of ground, and quantity of liquid in well, and only long experience will enable operators to judge when fresh cable can be safely fed out. Speed is modulated to cause the delivery of a blow at the extreme elastic limit of the rope, and any slack rope is liable to cause a crooked or flattened hole which checks progress and introduces many difficulties.

Under ordinary circumstances there appears to be no necessity to rotate the rope to secure the maintenance of a circular hole. The alternate and changeable strains caused by movements of

the beam, partial relief of weight at the moment of striking a blow, etc., cause the tools to spin and so reduce to a minimum the chances of the same spot being struck several times in succession. Nevertheless some drillers insist upon twisting the rope at the surface a certain number of times first to right and then to left.

The jars never come into play when running normally, but are the sole means of safety when trouble arises. Incautious or too ambitious drilling often causes the bit to become clogged by cavings or "*balling up*" in imperfectly pulverised material. In such cases the rope simply stretches on application of force, and no amount of direct pull on the rope will avail to effect release. It is then that the cable is relaxed until the upper link of the jars is felt to strike the lower, when, by careful adjustment of the temper screw, and rapid oscillation of the beam, a succession of violent upward blows can be administered to the tools, forcing them through the obstruction.

Manilla cable drilling cannot be successfully followed where there is a high level of liquid owing to the frictional resistance offered to the falling cable and tools. In very caving ground, where the maintenance of a high level of liquid might be of service, reliance has rather to be placed on keeping the column of tubes near the working face, thus diminishing the vibration that can scarcely be avoided in the presence of a long swinging rope.

Mention might be made of the danger attending the use of a string of tools in a large hole without the addition of guides to direct a straight blow on the working face. When a hard inclined stratum is struck, the swinging tools at intervals strike on one edge, with the result that the pin of the bit is fractured. Such an accident may be repeated a large number of times in succession in certain strata, unless the precaution is taken to attach guides or the speed of drilling is reduced.

Many little refinements of detail complete a rig of sterling merit capable of fine work in the hands of an experienced operator. In practice the walking beam is carefully balanced, and compensating weights are furnished to other parts to simplify

their movement. A derrick crane assists the handling of bits, and a laid-on water supply affords means of washing the derrick floor, cooling heated friction wheels or bearings, besides providing the water required for drilling. Shelter is arranged by galvanised iron sheeting, and in cold weather exhaust steam from the engine is led in pipes around the derrick floor. Electric lights are conveniently placed to permit all operations to be safely continued by night, and a turbine fan and steam hammer are frequently accessories to a complete outlying equipment.

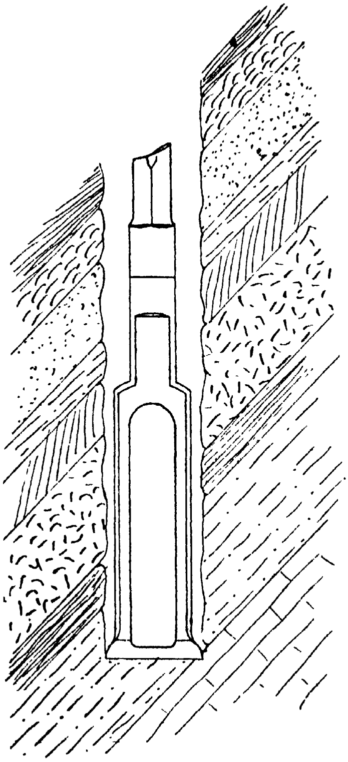

Fig. 50. – Bit Working in Inclined Strata.

Showing how a drill may easily run out of the vertical in inclined strata when it strikes a hard rock beneath a soft stratum.

Manilla cables were until recent years exclusively used for cable drilling. They are usually from 2 in. to $2\frac{3}{4}$ in. diameter, the strands are hawser laid, and they are composed of the finest quality long fibres. From 1-3 ft. of drilling is performed per foot of manilla cable, so that the charge for cable can be calculated at a rate per foot of drilling. A $2\frac{1}{4}$-in. cable, weighing 1.5 lbs. per foot., and costing 13.4 cents per lb.

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SPECIFICATION OF CABLE TOOL OUTFIT FOR 2,000 FEET.

Lining tube, $12\frac{5}{8}$ in., 10 in., 8 in., $6\frac{1}{2}$ in., and 5 in. internal diameter.

1 Steam boiler capable of evaporating with ease 1,500 lbs. of steam per hour at 100 lbs. pressure with fuel found in the district, fitted with feed pump, injector, and spares.
1 Horizontal 11 × 12-in. single cylinder reversing steam engine with pulley and flywheel, feed pump and feed water heater, with means for operating both throttle valve and reversing gear from the derrick, and ample spares and belting.
1 72 × 20-ft. wooden derrick and rig.
1 Set rig irons, 5-in. shaft.
1 No. 2 Barrett oilwell jack, complete with circle and bar.
1 1-ton Harrington chain hoist (T-beam) and swivel tool wrench, with $3\frac{1}{4}$ and 4 in. plates.
2 Sets 100-ft. telegraph cord wire and grooved wheels drilled.
6 No. 65 clothes line pulleys for use in elevating temper screw.
1 Set tool wrenches for 4 in. squares for $2\frac{3}{4} \times 3\frac{3}{4}$-in. joint.
1 " " $3\frac{1}{4}$ " 2×3 "
2 16-in. spudding bits $2\frac{3}{4} \times 3\frac{3}{4}$-in. joint, 4-in. squares, 7 flat threads.
3 All steel California pattern drilling bits to work inside $12\frac{5}{8}$-in. drive pipe, $2\frac{3}{4} \times 3\frac{3}{4}$-in. joint, 7 flat threads 4-in. squares, 4 ft. 6 in. long.
3 All steel California pattern drilling bits to work inside 10-in. drive pipe, $2\frac{3}{4} \times 3\frac{3}{4}$-in. joint, 7 flat threads 4-in. squares, 4 ft. 6 in. long.
3 All steel California pattern drilling bits to work inside 8-in. drive pipe, $2\frac{3}{4} \times 3\frac{3}{4}$ in. joint, 7 flat threads 4-in. squares, 4 ft. 6 in long.
3 All steel California pattern drilling bits to work inside $6\frac{5}{8}$-in. casing, $2\frac{3}{4} \times 3\frac{3}{4}$-in. joint, 7 flat threads 4-in. squares, 5 ft. long.
3 All steel California pattern drilling bits to work inside $5\frac{3}{16}$-in. casing, 2×3-in. joint, 8 sharp threads $3\frac{1}{4}$-in. squares, 5 ft. 6 in. long.
1 Tool gauge for each size bit.
1 Spudding shoe.
1 Box and pin template for $2\frac{3}{4} \times 3\frac{3}{4}$-in. joint, 7 flat 4-in. squares.
1 " " " 2×3-in. joint, 8 sharp $3\frac{1}{4}$-in. squares.
1 $1\frac{3}{4}$-in. B.B. temper screw to let out 4 ft. 8 in., with $1\frac{3}{4}$-in. lower parts for $2\frac{1}{8}$-in. dia. rope.
2 New era rope sockets for $2\frac{1}{8}$-in. cable, $2\frac{3}{4} \times 3\frac{3}{4}$-in. joint, 4-in. squares, 7 flat threads.
2 Sub-rope sockets for $2\frac{1}{8}$-in. cable, 2×3-in. joint, $3\frac{1}{4}$-in. squares, 8 sharp threads.
1 Set jars $5\frac{1}{4}$ in. dia. × 8-in. stroke, $2\frac{3}{4} \times 3\frac{3}{4}$-in. joint, 7 flat threads 4-in. squares.
1 Set jars $4\frac{3}{8}$ in. dia. × 8-in. stroke, 2×3-in. joint, 8 sharp threads $3\frac{1}{4}$-in. squares.
2 25-ft. stems $4\frac{1}{4}$ in. dia., $2\frac{3}{4} \times 3\frac{3}{4}$-in. joint, 7 flat threads 4-in. squares.
2 25-ft. stems $3\frac{1}{2}$ in. dia., 2×3-in. joint, 8 sharp threads $3\frac{1}{4}$-in. squares.
1 Conductor bailer $11\frac{5}{8}$ in. dia. × 10 ft. long.
1 Wrought-iron bailer 10 in. dia. × 19 ft. long.
1 " " 8 in. dia. × 19 ft. long.

2 Wrought-iron bailers, 7 in. dia. × 22 ft. long.
2 " " $5\frac{1}{2}$ in. dia. × 25 ft. long.
2 " " $4\frac{1}{2}$ in. dia. × 25 ft. long.
1 Spare bail and valve for all sizes of above.
1 "Morahan" sand pump for 10-in. drive pipe.
1 " " 8-in "
1 " " $6\frac{5}{8}$-in. casing.
1 " " $5\frac{3}{16}$-in. "
1 28-in. A.I. treble sheave pulley block for $\frac{7}{8}$-in. wire rope.
1 28-in. A.I. double " " $\frac{7}{8}$-in. "
1 Heavy $3\frac{1}{2}$ in. dia. round iron casing pulley block hook with double swivel.
1 Set (2) Scott's Mannington pattern casing elevators for 13-in. O.D. tubes.
1 " " " " " $10\frac{3}{4}$-in. "
1 " " " " " $8\frac{5}{8}$-in. "
1 " " " " " 7-in. "
1 " " " " " $5\frac{1}{2}$-in. "
1 Set driving clamps $4\frac{1}{2} \times 4\frac{1}{2} \times 14$-in. iron, with $2\frac{1}{4}$-in. bolts for clamping on to stem, 4 in. squares.
1 Set driving clamps $4\frac{1}{4} \times 4\frac{1}{4} \times 14$-in. iron, with $2\frac{1}{4}$-in. bolts for clamping on to stem, $3\frac{1}{4}$-in. squares.
1 Pair drive clamp wrenches.
1 Forged steel wedge ring for 13-in. O.D. tubes (spider).
1 Set of slips for above to fit 13-in. O.D. tubes.
1 " " " $10\frac{3}{4}$-in. "
1 Forged steel wedge ring for $8\frac{5}{8}$-in. O.D. tubes (spider).
1 Set of slips for $8\frac{5}{8}$-in. O.D. tubes.
1 " " 7-in. "
1 " " $5\frac{1}{2}$-in. "
1 Substitute $2\frac{3}{4} \times 3\frac{3}{4}$-in. 7 flat 4-in. squares pin to 2×3-in. box, 8 sharp $3\frac{1}{4}$-in. squares.
1 Substitute 2×3-in. 8 sharp $3\frac{1}{4}$-in. squares pin to $2\frac{3}{4} \times 3\frac{3}{4}$-in. box, 7 flat 4-in. squares.
1 $2\frac{3}{4} \times 3\frac{3}{4}$-in. box and pin joints, 7 flat threads 4-in. squares.
1 2×3-in. box and pin joints, 8 sharp threads $3\frac{1}{4}$-in. squares.
1 Spud 8 ft. long for $5\frac{3}{16}$-in. casing, 2×3-in $\times$ 8 sharp threads $3\frac{1}{4}$-in. squares.
2 2,250 lengths of $2\frac{1}{8}$-in. best quality Philadelphia manilla drilling cable.
2 2,250 ft. × $\frac{9}{16}$-in. sand line.
1 350 ft. × $\frac{7}{8}$-in. casing lines.
1 60 ft. × $1\frac{1}{4}$-in. dia. wire rope dead line (spliced).
6 $\frac{9}{16}$-in. wire rope clamps.
6 $\frac{7}{8}$-in. " "
2 $2\frac{1}{2}$-in. bull ropes and couplings.
1 Casing head, 2 outlets, for 10-in casing or drive pipe.
1 " " " $8\frac{1}{4}$-in. "
1 " " " $6\frac{5}{8}$-in. "
1 " " " $5\frac{3}{16}$-in. "
4 Sand line caps to suit above.
1 Each oil savers for $8\frac{1}{4}$-in., $6\frac{5}{8}$-in., and $5\frac{3}{16}$-in. casing heads.

FISHING TOOLS.

1 Fishing jar $4\frac{1}{2}$ in. dia., 30-in. stroke, 2×3-in. joint, 8 sharp threads $3\frac{1}{4}$-in. squares.
1 Slip socket for $6\frac{5}{8}$-in. casing, with slips for pin and collar of $2\frac{3}{4} \times 3\frac{3}{4}$-in. joint, 7 flat 4-in. squares, and bowls for 8-in. and 10-in drive pipe.
1 Slip socket for $5\frac{3}{16}$-in. casing, 8 sharp 4-in. squares, with slips for pin and collar of 2×3-in. joints.
1 Spare set of slips for each of above.
1 Horse-shoe trip knife.
1 Rope-knife sinker.
1 Rope-knife jar.
1 Ball-bearing swivel for rope knife.
1 Rope grab two-wing for $6\frac{5}{8}$ in. casing, screwed 2×3-in. joint, 8 sharp threads $3\frac{1}{4}$-in. squares.
1 Rope spear for $5\frac{3}{16}$-in. casing, screwed 2×3-in. joint, 8 sharp threads $3\frac{1}{4}$-in. squares.
1 Bailer grab for $6\frac{5}{8}$-in. casing, 2×3-in. joint, 8 sharp threads $3\frac{1}{4}$-in. squares.
1 Boot jack for $5\frac{3}{16}$-in. casing, 2×3-in. joint, 8 sharp threads $3\frac{1}{4}$ in. squares.

Wire Cable Drilling.—For wells down to 1,000 ft. steel wire cable drilling has rarely been successful, owing to the lack of elasticity which is the dominating factor in the cable process, but beyond that depth there is little difference in speed, and when there is a high level of fluid in the bore hole, or such is rendered desirable for the purpose of suppressing gas, reducing cavings, etc., there is no doubt about its efficacy. No great modification in the standard plant is required, the main difference lying in the replacement of the temper screw clamp, the rope socket, and preferably larger pulleys and drums for the rope to pass over. Complications were at one time anticipated in the difficulty of rotating a wire rope, but the increasing neglect of this doubtfully beneficial precaution in all but perhaps a few localities has removed one of the chief objections to its introduction.

Flowing wells may be continued in comparative comfort and with little delay by wire rope drilling, the drill working quite freely in the column of liquid as the casing head carries off the discharged oil. Its especial value, however, lies in the feasibility, by its use, of drilling in columns of water or mud, and thus evading so many of the casing troubles that are such a constant source of annoyance, delay, and expense in some oil-fields, like those of California.

Steel wire cables are usually from $\frac{3}{4}$-1 in. in diameter. Various types of rope sockets are described on p. 331, some of which are designed to automatically rotate the drill in one direction. From $\frac{3}{4}$-$1\frac{1}{2}$ ft. of cable per foot of hole drilled represents the wastage in the California oil-fields.

Circulating Cable System.—The utilisation of a high level of water in the hole during drilling has long been practised for averting excessive caving, and preventing the too free admission of oil and gas until the requisite depth has been attained, and other advisable operations completed. Water thus admitted was naturally rendered more or less muddy by the churning action of the tools, but the true importance of thick muddy fluids has only recently been appreciated and acted upon where difficult caving ground had to be pierced to reach a certain horizon. The importance of this action has been demonstrated by investigations conducted by officials of the United States Bureau of Mines.[1]

The destructive action of clear water compared with that of a more viscous thick clay solution may be discerned by observing the difference of behaviour in two streams of fluid over say a sandy path. Whilst the former erodes a channel and transports particles, the latter fills up irregularities between particles and moves along without disturbing the bed over which it flows. The same action proceeds in wells. Whilst clear water will tend to dissolve, wash out, and remove sandy particles or layers between or amidst argillaceous strata, a thick mud will rather produce the opposite effect and tend to plaster up porous seams.

A second feature of importance is the increased pressure on the side of the bore hole due to the extra weight of a mud-laden fluid over clear water. Whereas clear water weighs 62.5 lbs. per cubic foot and exerts a pressure of 43 lbs. per square inch per 100 ft. of depth, a good mud weighs 78 lbs. per cubic foot and exerts a pressure of 53 lbs. per square inch per 100 ft. of depth. Thus at a depth of 1,500 ft. clear water would exert a pressure of 645 lbs. per square inch against 795 lbs. per square inch for a good mud. This character has been practically utilised with great success for

[1] Technical Papers, 15 and 66, "Petroleum Technology."

shutting in oil and gas sources which could not be overcome by ordinary methods (see p. 392).

Cable drilling can be performed in thick muds, but steel wire lines must replace ordinary manilla cables. The well is kept filled by a pump, and when a certain amount of drilling has been performed the debris is cleared out in the ordinary way by sand pumps or bailers. The less the freedom with which the disintegrated material mixes with mud the more frequently it is necessary to clean out the hole.

Inexpensive additions are necessary to convert a cable rig into a circulating plant. Drilling is continued with a steel wire line through a casing head and oil saver, whilst a circulation is maintained down the inside of the casing and up around its exterior. This process has proved especially efficacious where caving difficulties combined to impede drilling and check the movement of the column of casing. The saving of a single column of casing in a deep well may itself represent several thousand dollars, but it is in time that the greatest advantages lie.

Fig. 51 shows the method adopted. A mud is prepared to suit the circumstances, and two suitably coupled-up pumps, capable of interchange at any moment, give the desired pressure to maintain a circulation.

A special feature of this process is the "*swinging spider*," which enables the casing to be raised and lowered without withdrawing the tools. As it is essential that the casing be kept within a few feet of the bottom of the hole during drilling, the advantage of this appliance is apparent.

Rope Sockets.—Connections between a manilla or wire cable and the string of tools is made by a rope socket. The lower part is internally screwed to fit the tools, whilst the upper is often in two parts, and internally bored with a taper hole into which the rope, increased in bulk by plaiting in additional strands, is firmly drawn. One popular type has a tapered side orifice into which the bunched-up cable end is tightly drawn and then trimmed.

Wire rope sockets are often constructed with conical recesses in the body of the tools corresponding with wedge-shape segments

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[1] Technical Papers, 15 and 66, "Petroleum Technology."

that firmly grasp the rope when weight is applied. One type of socket contains a simple conical recess, tapering downwards, into which the rope is thrust, the strands spread out, and the whole fixed in position with white metal or lead.

Wire rope sockets have been designed to take advantage of the spin transmitted to a wire rope. One such type has a ratchet which ensures the rotation of the tools in one direction. Another is provided with a ball-bearing that makes the rotation of the tools quite independent of the spin of the rope.

Tool Joints and Tightening Apparatus. — Nearly all modern tool joints have taper threads of from six to eight threads per inch. Both pin and socket ends are carefully turned, screwed, and chased to gauge, so that they can be screwed up by hand wrenches to within the thickness of a sheet of tin plate. The joints of cable tools are screwed to butt, and loosened by massive tool wrenches, the ends of which are either levered from a half circle bolted to the derrick floor, or driven home by blows from a sledge hammer. Tool joints must be absolutely interchangeable, kept quite clean, and must always be preserved by thread protectors when not in use.

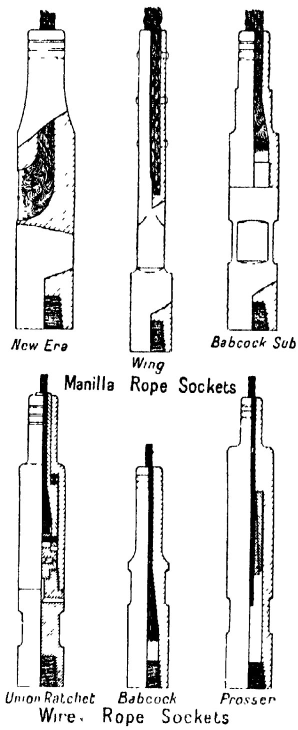


Fig. 52.—American Cable Tools.

The best and most universally adopted apparatus for tightening up and loosening joints is the Barrett Oil-well "Jack" shown in Fig. 53.

Percussion Bits.—Several representative forms of percussion drills appear in Fig. 54. Cable drillers generally prefer the thicker type as shown in Fig. 54, *b*, and 54, *c*, whilst for pole tool

systems the thinner, sharper variety illustrated in Fig. 54, *e*, is preferred.

There is a modern tendency to increase the length of drills, and in the smaller sizes they are often all steel, instead of having only a lower part of steel welded on to an iron shank.

Special shaped bits are sometimes used for particular duties. A "Star" bit (Fig. 54, *f*) is effective in rounding up a hole which for some reason is not quite circular, and bits with side wings are in general favour in Russia and Roumania.

Eccentric Bits.—It is possible in some kinds of strata to bore a hole several inches larger than the diameter of the bit by means

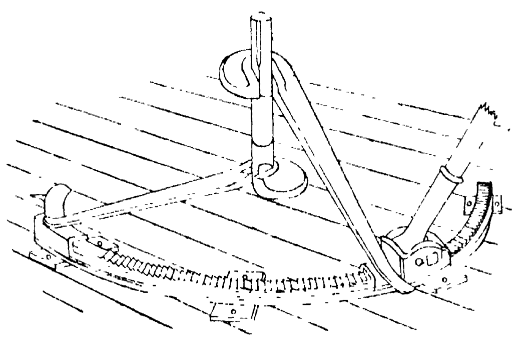


Fig. 53. Method of Tightening up Joints of Drilling Tools with Barrett Oil-Well "Jack."

of eccentric bits. These drills, whilst passing freely through the casing, have an eccentric cutting edge whereby a hole larger than the diameter of the bit is made. Divergent views are held concerning the value of the many designs of eccentric bits in use. The objects aimed at will be self-evident from the features shown in Fig. 55. As a matter of fact, one form will give better results in certain ground than another, and only trial determines the advantage of any particular class in a certain locality. Eccentric bits should be nicely balanced by the judicious distribution of metal, although this feature is not often taken into account.

By their use in Galicia and Roumania, it has been possible without the aid of under-reamers to carry strings of casing behind the drill for many hundreds of feet, where formerly a reduction of

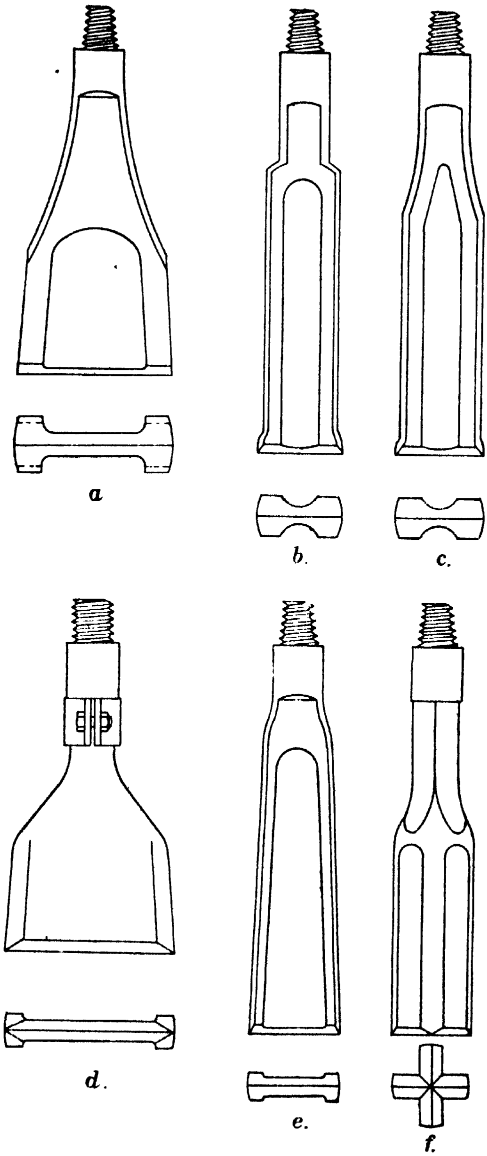


Fig. 54.—Percussion Drilling Bits.

a. "Spudding" Bit.
b. "Mother Hubbard" (American).
c. "Californian" (American).
d. "Russian."
e. "Canadian or Galician."
f. "Star."

diameter was often necessary much earlier to secure the free action of the drill.

Under-reamers.—Geological formations characterised by alternations of loose caving ground and hard rock can, as a rule, only be successfully dealt with by percussion tools by keeping the casing near the bit. As the casing shoe, which is necessarily larger by an inch or more than the drill, cannot be driven past hard beds without danger, the hole is enlarged, by means of an under-reamer, to a little more than the size of the outside diameter of the shoe of the lining tubes. Two types of under-reamers used in conjunction with percussion drills are illustrated. That shown in Fig. 56, *b*, where the expanding cutters are kept extended by internal springs, is known as the Austrian. Fig. 56, *a*, shows the Russian type, where the under-reaming cutters are extended by an external spring. In both classes the cutters are designed to expose a rounded surface to the tubing during their descent in the casing.

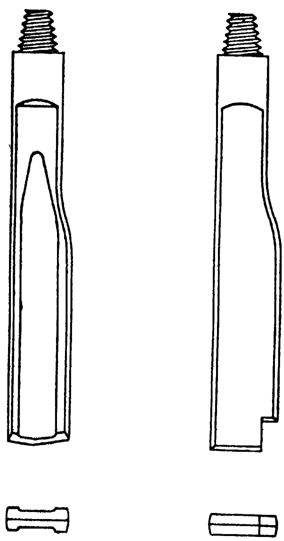


Fig. 55.—Eccentric Percussion Drilling Bits.

Both of the above types of under-reamers may be incorporated in the string of tools, thereby enabling both drilling and under-reaming to be conducted simultaneously.

A successful combination under-reaming drill is shown in Fig. 57, where it will be seen that the cutting edges of the drill are shaped to assist in the extension of the two wings.

Another popular class of under-reamer is used for independently enlarging the hole after drilling has progressed some distance. An example of such is represented in Fig. 58. These latter are used when some difficulty is experienced in maintaining the rotation of cable tools when an under-reamer is attached to the string of tools.

Handling and Dressing Bits.—The dressing or trimming

(sharpening can scarcely be applied to the operation in most cases) and tempering of large-sized drills impose laborious duties on the attendants, and ingenious devices have been introduced to facilitate the work where neither a workshop nor extra men are often available. A small steam turbine-propelled blower for the forge is now

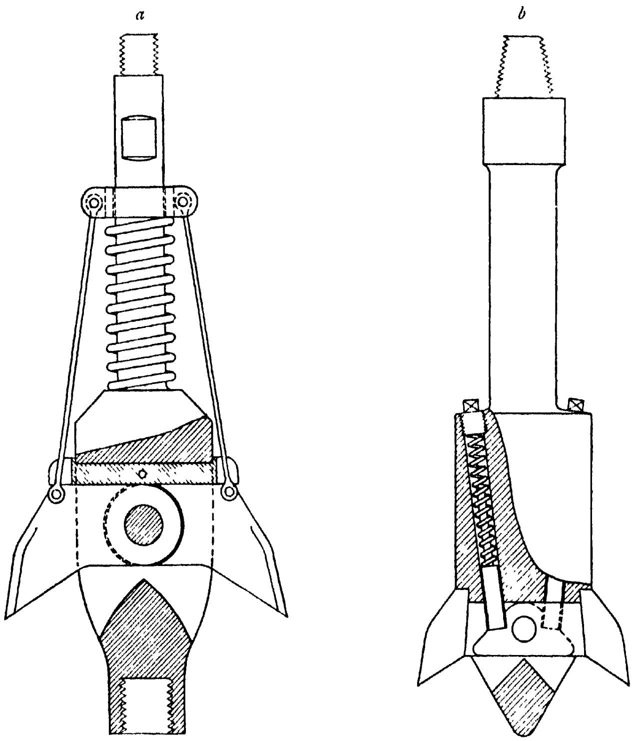


Fig. 56.—Under-reamers.
a. Russian. b. Austrian.

a common adjunct to a drilling equipment, but where bellows are retained, a rope is usually led from the handles of the bellows to some reciprocating part of the rig to perform the blowing. For the dressing of bits steam hammers are now procurable that can be cheaply erected at or near the well, and enable a blow to be delivered at almost any required angle.

A light derrick crane (Fig. 59) is an acceptable contribution to a modern rig, enabling the tools to be easily manipulated during repairs. In conjunction with this crane a swivel wrench of novel design, known as the "Barrett," is often employed to simplify handling.

On p. 340 is a drawing of a blacksmith's forge for burning

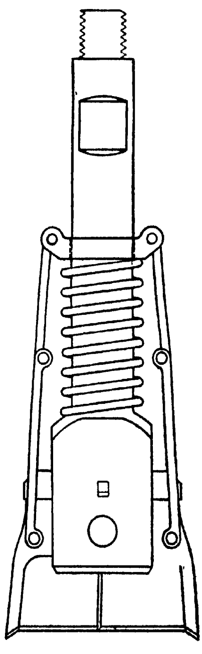


Fig. 57. Biering Under-reaming Bit.

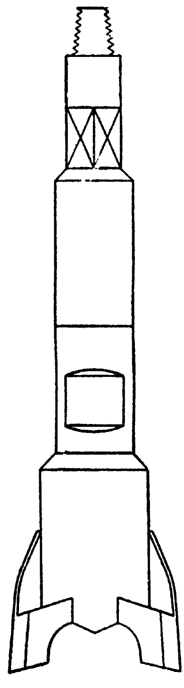


Fig. 58.—Double Under-reamer.

oil fuel. An ordinary fan is used for the air blast, and combustion is effected in a fire-brick side chamber prior to admission to the furnace proper.

The drills are dressed to suit the character of strata being penetrated. In soft sticky formations no cutting edge is given to the bit, and they really constitute rammers, having an almost flat

base. In hard ground a cutting edge is given to the tool. Wear is mainly confined to the side edges, causing a gradual reduction of

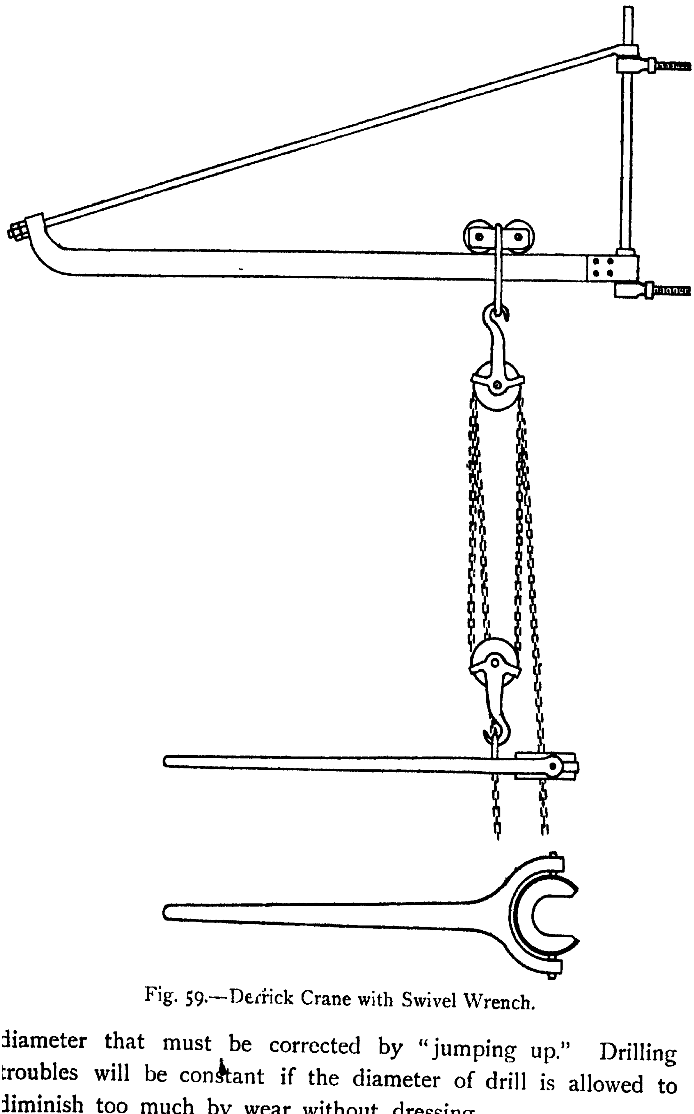


Fig. 59.—Derrick Crane with Swivel Wrench.

diameter that must be corrected by "jumping up." Drilling troubles will be constant if the diameter of drill is allowed to diminish too much by wear without dressing.

Bit gauges are always kept at the well to aid the dressing by ensuring a correct outside sweep to coincide with the diameter.

Appliances for Removing Debris.—As ground is pulverised by percussion tools the detritus or puddled mud formed has to be cleared away to enable the tools to fall freely and deliver clean

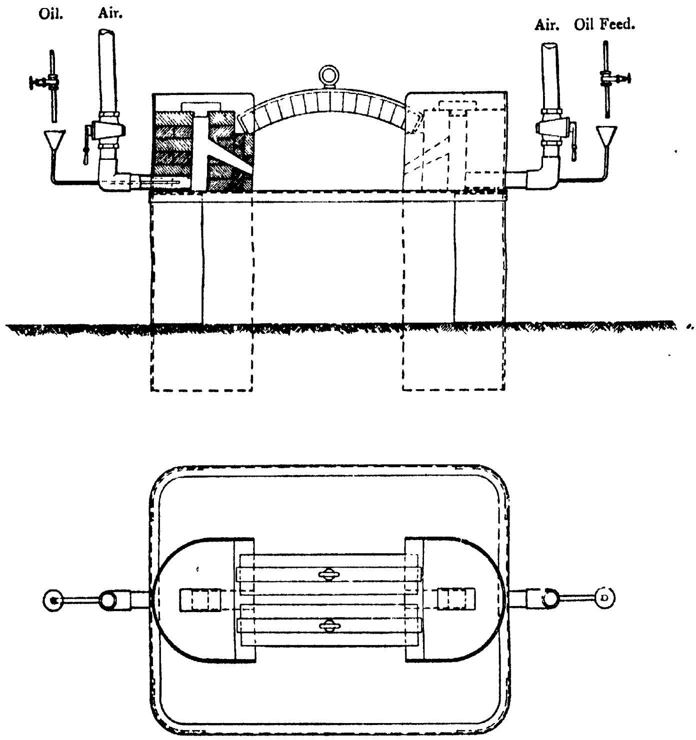


Fig. 60.—Blacksmith's Forge for Burning Oil.

unchecked blows to unbroken strata. The most common appliances for rapid work are known as bailers and sand pumps.

Bailers.—Bailers are cylindrical iron vessels from a few feet to 30 ft. in length, provided with a valve opening inwards at their lower extremity. They are used for the removal of mud which does not settle rapidly or compactly after the drill has been brought to rest and raised from the well. There is usually some form of pick or extension which assists to stir up the debris when the bailer

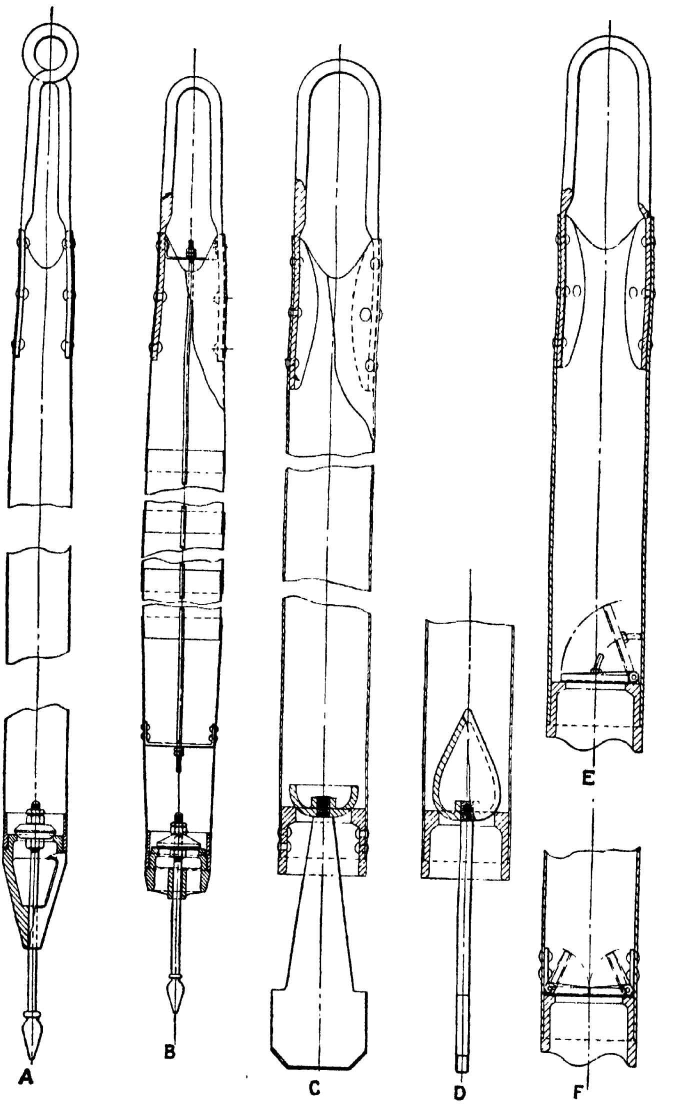


Fig. 61.—Types of Bailers.

A, B. Russian. C, D. "Regular" (C with bailer valve).
E, F. "Conductor" (F with double valve).

is quickly and repeatedly raised a few feet from the bottom and allowed to fall again. Fig. 61 shows a few normal types whose dimensions and length are varied to suit circumstances.

Bailers are usually made by riveting together lap-welded sections of sheet iron and then soldering, but welded spiral bailers are now commonly made in long lengths.

Bailers with a disc valve are emptied by lowering on to an extension of the guide spindle attached to the valve, those with flap valves are lowered on to a vertical bar which forces up the valve.

Sand Pumps.—Sand pumps, in addition to being provided with a lower valve, have a piston which when worked causes the debris to be drawn into the bailer, where it is held by the lower valve whilst being raised. Special features characterise different makes, but the essentials of all are the same. A number of typical designs are shown in Fig. 62.

B represents a simple sand pump where, during lowering on a line, the plunger is at the top of the chamber, but on reaching the bottom the body comes to rest, and the plunger descends by its own weight. By alternately raising and lowering the sand line some feet beyond the full stroke of the plunger, the debris is agitated by the movement of the pump and drawn into the vessel, where its return is prevented by the closing of the lower valve.

Some debris is as difficult to remove from the vessel when once introduced as it is to induce its initial entry. D and E show three types of sand pumps designed to minimise this inconvenience. In B, C, D, and E a knuckle joint enables the bailer to be easily inverted for emptying the contents. C, E, and F illustrate means for quickly and simply removing the lower valve, so affording facilities for assisting the removal of compacted material.

A good Russian type of sand pump for cleaning wells of large diameter is shown in A, where a piston operates in an upper chamber of reduced diameter.

The plungers of sand pumps are usually packed with old rope or belting. The valves, if not of the metal disc type, have leather seatings.

Augers.—Before wells have reached a great depth they are sometimes cleared of thick material by means of shell or screw augers, lowered on and rotated by rods. Shell augers partake of numerous

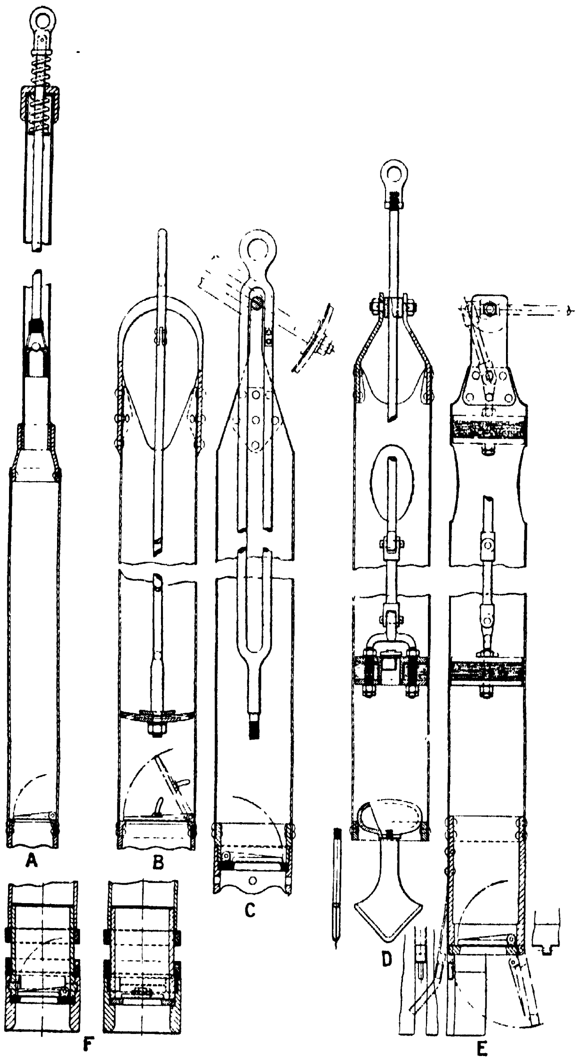


Fig. 62.—Types of Sand Pumps.

A. Russian type, with separate piston chamber.
B. Common type.
C. ,, ,, with extractable valve.
D. Knuckle joint type with pick valve.
E. ,, ,, with hinged valve seat.
F. Type of extractable valves.

designs, some having closed bodies, others open; some are fitted with valves to retain their contents, others have no such provision.

Canadian System of Drilling.—Developed beyond recognition, the modern drill known under the designation of Canadian rig is the modified adaptation of a pole tool system initiated in Canada and subsequently developed in Galicia and Roumania. Originally ash poles were the media of connection between the tools and the surface, but deeper drilling and scarcity of suitable timber led to their substitution by square or round iron rods. No better all-round rig could be suggested for prospecting, as the positive action of the rods affords a means of attacking all kinds of material, and presents facilities for the use of under-reamers.

The Canadian rig is a simple woodwork framing in which one shaft and two "*spools*" running in bearings transmit the various motions desired. The drive is taken by a pulley attached to the main shaft, on which are also keyed two "*band*" pulleys which communicate by belting with two spools running immediately overhead in the upper part of the framework. Keyed to one extremity of the main shaft is a disc crank which, through the medium of a "*pitman*" or connecting rod, transmits an oscillating movement to an overhead, pivoted walking beam when the engine is run. The band and spool pulleys are flanged to prevent the driving belts from slipping off, as the belts are always left loosely in position. The spools are brought into action by "*jockey pulleys*" which are drawn firmly inwards by levers against the belts. One spool wheel operates the sand line when cleaning out the well, the other is used for lowering and raising the rods and tools as they are inserted or withdrawn from the well.

Near the fulcrum of the walking beam is attached a "*slipper out*," which is used for feeding the tools during drilling, instead of a temper screw. It is merely a worm gear or a clutch gear with double pawl attached to a spindle upon which is coiled a chain leading to the "*spring pole*" overhanging the well. At the end of the beam the chain several times encircles a fitting, so that when the tools are released by the clutch gearing the greater part of the weight is taken by the beam and not by the clutch.

Fig. 63 shows the general arrangement of a Canadian rig.

Casing duties are performed by a line that connects to the

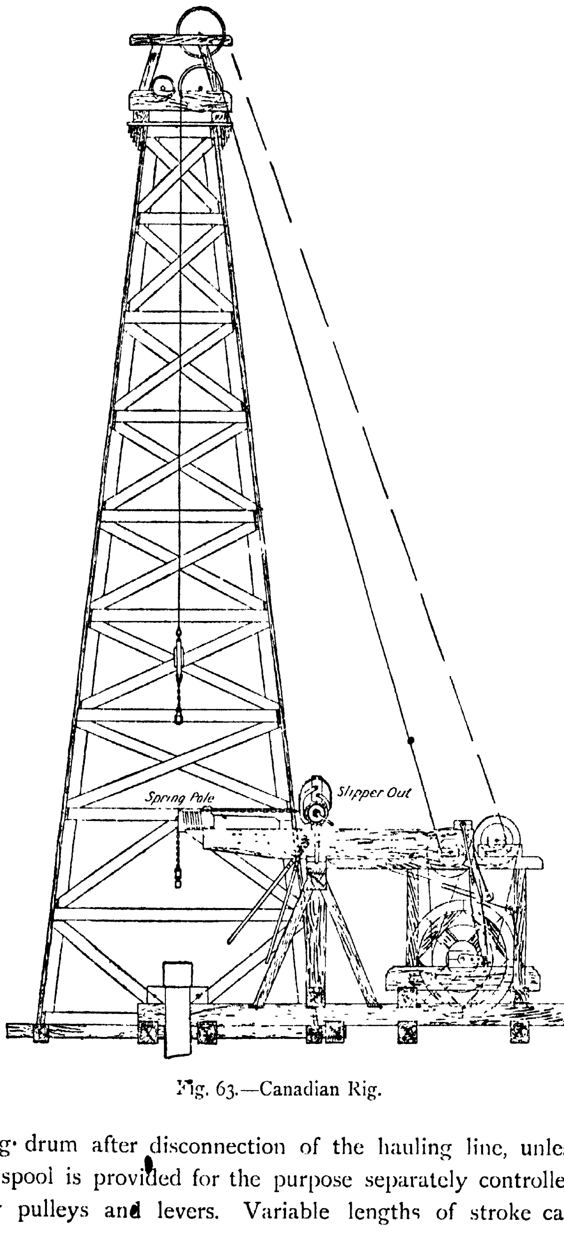


Fig. 63.—Canadian Rig.

hauling drum after disconnection of the hauling line, unless an extra spool is provided for the purpose separately controlled by jockey pulleys and levers. Variable lengths of stroke can be

imparted to the tools by placing the crank-pin in one of the several holes on the crank disc.

Spudding is performed by leading the drilling cable over two grooved pulleys attached to the walking beam at equal distances on each side of the fulcrum and thence over the top pulley, a movement on the beam thus transmitting a reciprocating motion to the string of tools. Canadian tools closely resemble those used for cable drilling. The jars are not omitted as they constitute a safeguard that should never be neglected. Guides are often bolted to the stem to ensure the delivery of a direct blow, and an under-reamer is often part of the complement of a string of tools to enable the casing to closely follow the tools.

The poles are of 2-2½ in. hexagonal or round trimmed ash, in lengths of about 18 ft., to the extremities of which are riveted iron straps which partially encircle the rod and have a screwed pin or a box joint. Sometimes two such rods are coupled together by means of two iron straps encircling the pole, making 36-ft. lengths. The joints are always screwed taper to take up wear, and there are six to eight threads to the inch. The figures below give the Canadian standard sized joints for poles and other attachments :—

No.	Diam. at Point.	Diam. at Shoulder.	Length	Thread, per Inch.	Size of Wrenches.	Diam. of Collar.
	Inches.	Inches.	Inches.		Inches.	Inches.
1	$1\frac{1}{2}$	$2\frac{1}{4}$	3	8	$2\frac{1}{4}$	$3\frac{1}{4}$
2	$1\frac{3}{4}$	$2\frac{3}{4}$	4	8	3	$4\frac{1}{8}$
3	2	3	4	8	3	$4\frac{3}{8}$
4	$2\frac{1}{2}$	$3\frac{1}{2}$	4	8	$3\frac{1}{2}$	$4\frac{7}{8}$

Iron poles $\frac{7}{8}$-$1\frac{1}{8}$ in. diameter are largely used in place of ash poles, although the latter have the advantage of reduced weight when deeply immersed in liquid. The metal rods must be annealed at intervals in a furnace, to counteract crystallisation that in time becomes a fruitful source of fractures unless checked.

The rods are raised and lowered by a pole box and swivel on a $\frac{7}{8}$-in. steel wire rope worked by one of the spools, a suitable fork being pushed beneath the collar of each joint as it reaches the mouth of the well. The descent of the rope after a rod has

been raised and placed aside in the derrick is brought about by a heavy rope weight coupled to the rope above the swivel-screwed joint by which they are lifted. When the tools and rods have been lowered to the bottom of the well, suitable short lengths of rods are attached to give the desired distance to couple up with the feed chain on the walking beam by a drill swivel, the feed being adjusted by the slipper-out clutch during work.

Modern Canadian rigs are often constructed of steel and adapted to perform wire cable drilling, thus greatly enhancing their value by permitting accelerated drilling speeds in suitable strata.

In addition to the ordinary sand pumps and bailers which can be operated by a steel wire line, augers can be lowered and rotated by the rods.

Specification of Complete Canadian Rig and Tools for Drilling to a Depth of 2,000 Feet.

For lining tubes $12\frac{3}{8}$ in., 10 in., 8 in., $6\frac{1}{2}$ in., and 5 in. internal diameter.

1 Steam boiler capable of evaporating with ease 1,500 lbs. of steam per hour at 100 lbs. pressure with fuel found in the district, fitted with feed pump, injector, and spares.

1 Horizontal $11\frac{1}{2} \times 12$-in. single cylinder reversing steam engine, with pulley and flywheel, feed pump and feed water heater, with means for operating both throttle valve and reversing gear from the derrick, and ample spares and belting.

1 Wood or steel derrick, 60 ft. high × 18 ft. base.

1 All steel rig, including walking beam, snatch post, husk blocks, sheave block, C.I. boxes babbited for crankshafts, spools, tighteners, saddle bolts, belting, etc.

Wire Ropes.

1 $\frac{7}{8}$-in. draw line, 120 ft. long, 6 × 19 construction, fitted with two thimbles.

1 $\frac{5}{8}$-in. casing line, 650 ft. long, 6 × 19 construction, fitted with one thimble.

2 $\frac{9}{16}$-in. sand lines, 2,500 ft. long, 6 × 12 construction, fitted with two thimbles.

2 $\frac{7}{8}$-in. drilling cables, 2,500 ft. long, 6 × 19 construction, fitted with one thimble.

Drilling Bits.

2 15-in. spudding bits, 3 × 4-in. pin, 420 lbs.

3	Drilling bits to work inside	$12\frac{3}{8}$-in. I.D. drive pipe, 3 × 4-in. joint, $4\frac{1}{2}$-in. squares, 420 lbs. each.
3	" " "	10-in. I.D. drive pipe, 3 × 4-in. joint, $4\frac{1}{2}$-in. squares, 375 lbs. each.
3	" " "	8-in. I.D. drive pipe, $2\frac{1}{2} \times 3\frac{1}{2}$-in. joint, 4-in. squares, 320 lbs. each.

3 Drilling bits to work inside $6\frac{1}{2}$-in. I.D. drive pipe, $2\frac{1}{2} \times 3\frac{1}{2}$-in. joint. 4-in. squares, 270 lbs. each.
3 „ „ „ 5-in. I.D. drive pipe, $1\frac{3}{4} \times 2\frac{3}{4}$-in. joint, 3-in. squares, 180 lbs. each.

Eccentric Bits.

3 Eccentric bits to work inside $12\frac{5}{8}$-in. I.D. drive pipe, O.D. of shoe being $14\frac{1}{8}$ in., 3×4-in. joint, $4\frac{1}{2}$-in. squares, 450 lbs. each.
3 „ „ „ 10-in. I.D. drive pipe, O.D. of shoe being 12 in., 3×4-in. joint, $4\frac{1}{2}$-in. squares, 400 lbs. each.
3 „ „ „ 8-in. I.D. drive pipe, O.D. of shoe being $9\frac{1}{2}$ in., $2\frac{1}{2} \times 3\frac{1}{2}$-in. joint, 4-in. squares, 300 lbs. each.
3 „ „ „ $6\frac{1}{2}$-in. I.D. drive pipe, O.D. of shoe being $7\frac{1}{16}$ in., $2\frac{1}{2} \times 3\frac{1}{2}$-in. joint, 4-in. squares, 250 lbs. each.
3 „ „ „ 5-in. I.D. drive pipe, O.D. of shoe being $6\frac{1}{16}$ in., $1\frac{3}{4} \times 2\frac{3}{4}$ in. joint, 3-in. squares, 150 lbs. each.

Sinkers.

1 5-in. sinker, 25 ft. long, 3×4-in. joint, $4\frac{1}{2}$ in. square.
1 5-in. „ 15 „ 3×4-in. „ $4\frac{1}{2}$-in. „
1 $4\frac{1}{2}$-in. „ 25 „ $2\frac{1}{2} \times 3\frac{1}{2}$-in. „ 4-in. „
1 $3\frac{1}{2}$-in. „ 25 „ $1\frac{3}{4} \times 2\frac{3}{4}$-in. „ 3-in. „
1 3-in. „ 20 „ large pole joints for sand pump and fishing.

Jars.

1 $6\frac{1}{4}$-in. drilling jar, 3×4-in. joint, $4\frac{1}{2}$ in. squares.
1 $5\frac{3}{8}$-in. „ $2\frac{1}{2} \times 3\frac{1}{2}$-in. „ 4-in. „
1 $4\frac{1}{8}$-in. „ $1\frac{3}{4} \times 2\frac{3}{4}$-in. „ 3-in. „
1 $5\frac{3}{8}$-in. fishing jar, $2\frac{1}{2} \times 3\frac{1}{2}$-in. „ 4-in. „
1 $4\frac{1}{8}$-in. „ $1\frac{3}{4} \times 2\frac{3}{4}$-in. „ 3-in. „

Substitutes.

1 Substitute 4×3-in. box, $2\frac{1}{2} \times 3\frac{1}{2}$-in. pin.
1 „ 4×3-in. pin, $2\frac{1}{2} \times 3\frac{1}{2}$-in. box.
1 „ 4×3-in. box, large pole pin.
1 „ $2\frac{1}{2} \times 3\frac{1}{2}$-in. box, $1\frac{3}{4} \times 2\frac{3}{4}$-in. pin.
1 „ $2\frac{1}{2} \times 3\frac{1}{2}$-in. pin, $1\frac{3}{4} \times 2\frac{3}{4}$-in. box.
1 „ $2\frac{1}{2} \times 3\frac{1}{2}$-in. box, large pole pin.
1 „ $1\frac{3}{4} \times 2\frac{3}{4}$-in. box, „ „
1 „ $1\frac{3}{4} \times 2\frac{3}{4}$-in. pin, large pole box.
1 „ large pole pin, small pole box.
1 „ large pole box, small pole pin.

Drill Poles.

84 Special iron drill poles, each 36 ft. long by 1 in. dia. = 3,024 ft., small pole joint.
8 Tubular hand poles, 2 each 5 ft., 6 ft., 10 ft., and 15 ft., for each size joint.
20 Pairs small pole joints for welding.

Wrenches.

2 Heavy tool wrenches for 4½-in. squares.					
2	„	„	„	4-in.	„
2	„	„	„	3-in.	„

2 Knock wrenches.
1 Catch wrench.
2 Chain levers (1 heavy and 1 light).
1 Key wrench for iron poles.

Swivels.

2 Pole swivels with chain for 1-in. poles.
2 Sand pump swivels.
1 Pole hook.
1 Sand pump hanger and chain.

Mud and Sand Pumps.

1 12-in. mud pump, 6 ft. long, with hinged bail and large pole pins.

2 10¾-in.	sand pumps,	18	ft. long,	with large	pole pin.
2 8⅝-in.	„	18	„	„	„
2 7-in.	„	18	„	with small	„
2 5½-in.	„	36	„	„	„
2 4⅞-in.	„	36	„	„	„

1 Spare valve for each of above.

Wedge Rings and Wedges.

(Heavy Pattern.)

1 Steel plate suitable for 13-in. and 10¾-in. O.D. drive pipe.

1	Set of	wedges for	13-in.	O.D.	drive pipe.
1	„	„	10¾-in.	„	„

1 Steel plate suitable for 8⅝-in. and 7-in. O.D. drive pipe.

1	Set of	wedges for	8⅝-in.	O.D.	drive pipe.
1	„	„	7-in.	„	„

1 Steel plate suitable for 5½-in. O.D. drive pipe.
1 Set of wedges for 5½-in. O.D. drive pipe.

Elevators.

1	Pair	Scott's	Mannington	elevators for	13-in.	O.D.	drive pipe.
1	„	„	„	„	10¾-in.		„
1	„	„	„	„	8⅝-in.		„
1	„	„	„	„	7-in.		„
1	„	„	„	„	5½-in.		„

Blocks.

1 Extra heavy quadruple block with 15-in. sheaves and shackle bronze-bushed throughout.
1 Extra heavy treble block with 15-in. sheaves and swivel head bronze-bushed throughout.
2 Light blocks for $1\frac{1}{4}$-in. rope.

Wire Rope Drilling Swivels and Clamps.

1 Patent wire rope swivel, 4×3-in. box.
1 " " " $2\frac{1}{4} \times 3\frac{1}{2}$-in. "
1 " " " $1\frac{3}{4} \times 2\frac{3}{4}$-in. "
1 Heavy wire rope drilling clamp.

Fishing Tools.

1 Slip socket for recovering 1-in. iron pole in 8-in. I.D. drive pipe, with bonnets for 10-in. and $12\frac{3}{8}$-in. $2\frac{1}{2} \times 3\frac{1}{2}$-in. joint.
1 Slip socket for recovering 1-in iron poles in 5-in. I.D. drive pipe, with bonnets for $6\frac{1}{2}$-in. and $1\frac{3}{4} \times 2\frac{3}{4}$-in. joint.
2 Spare sets slips for each size.
1 Hook with dog for 10-in. hole, $2\frac{1}{2} \times 3\frac{1}{2}$-in. joint.
1 " " $6\frac{1}{2}$-in hole, $1\frac{3}{4} \times 2\frac{3}{4}$-in. "
1 Horn socket, $12\frac{3}{8}$-in. hole, $2\frac{1}{2} \times 3\frac{1}{2}$-in. joint.
1 " " 8-in. " $2\frac{1}{2} \times 3\frac{1}{2}$-in. "
1 " " $6\frac{1}{2}$-in. " $1\frac{3}{4} \times 2\frac{3}{4}$-in. "
1 " " 5-in. " $1\frac{3}{4} \times 2\frac{3}{4}$-in. "
1 Wire rope knife, large pole pin joint.
1 " " sinker "
1 " " jar "
1 " " hook "
1 Wire rope spear, $1\frac{3}{4} \times 2\frac{3}{4}$-in. joint.
1 " grab, $1\frac{3}{4} \times 2\frac{3}{4}$-in. "

Spuds.

1 Spud 10 ft. long for 10-in. hole, 4×3-in. joint.
1 " " $6\frac{1}{2}$-in. " $2\frac{1}{2} \times 3\frac{1}{2}$-in. "

Welding on Joints.

2 Pairs 3×4-in. joints for welding.
2 " $2\frac{1}{2} \times 3\frac{1}{2}$-in. " "
2 " $1\frac{3}{4} \times 2\frac{3}{4}$-in. " "
3 Pole joints for welding.

Swedges.

1 Swedge fluted for working inside 10-in. I.D. drive pipe.
1 " " " 8-in. " "
1 " " " $6\frac{1}{2}$-in. " "
1 " " " 5-in. " "

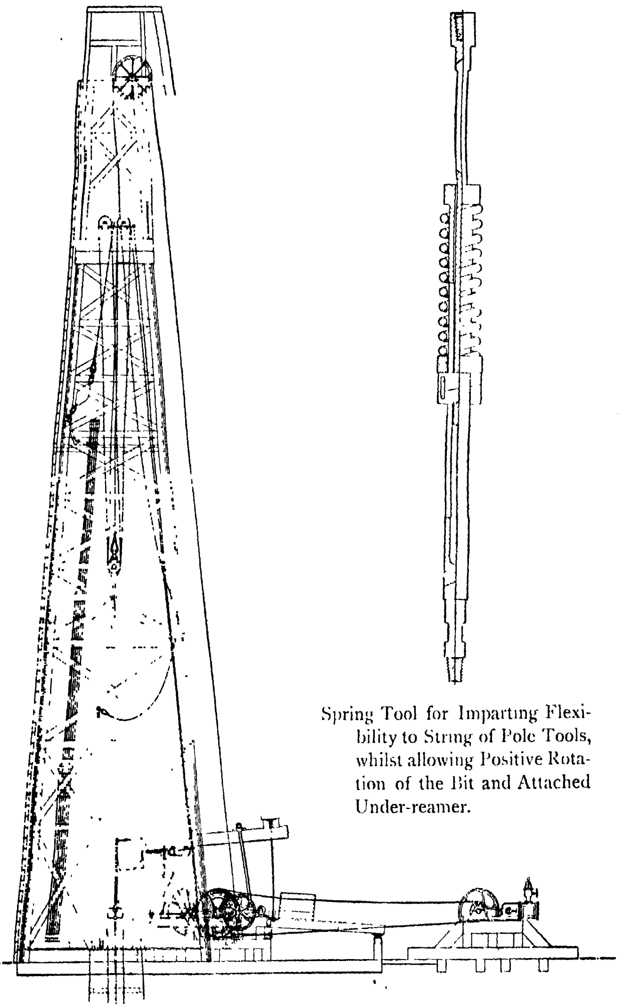
DRIVE CLAMPS.

1 Pair drive clamps and bolts to fit 4½-in. squares.
1 „ „ „ 4-in. „
1 „ „ „ 3-in. „
1 Set spanners.

Russian Freefall System.—The large diameter of wells in the Baku oil-fields, and the specially caving nature of the strata met with, have led to the adoption of a modified pole tool system which well suits the local conditions. The tools consist of a chisel or bit, under-reamer, sinker bar, and freefall, connected by 1¼-in. square iron rods which extend to the surface. The tools are operated by a geared frame of heavy design driven by belting from an engine or motor in the derrick. The geared frames vary somewhat in design, but they are all provided with means of operating four distinct shafts or combinations which drive by gearing or otherwise three drums and a crankshaft. One slow geared shaft in the front of the frame is fitted with a drum and powerful side brake, and is used for raising and lowering the tools through a distance of about 50-60 ft. as the rods or tools are being connected or disjointed. Another larger drum geared for high speed is used for raising and lowering the bailer and sand pump, and a third drum shaft, also in combination with a brake, operates the heavy pulley blocks which are used for manipulating the casing. One of the above shafts, which can be disconnected from the drum, or a fourth shaft, is fitted with crank discs, which, by connecting rods, impart an oscillating motion to a walking beam pivoted on the upper part of the frame. The cranks are provided with holes at different radii to enable a varied stroke to be given to the beam by altering the position of the crank-pins, and means are arranged for throwing in and slipping out of gear the various drums as occasion demands.

The tools are screwed together singly and lowered into the mouth of the well by means of either a 1½-in. English welded chain, or a 1½-2½-in. steel wire cable attached to the front drum, a very heavy swivel hook with safety catch being attached to the chain or rope for the purpose. The 1½-in. square rods are generally 21 ft. long, screwed with taper threads, and are left coupled up in pairs to make 42-ft. lengths after the depth of

the well exceeds about 70 ft. A sheet-iron cap with a slotted hole sufficiently large to pass the collars of the rods is placed



Spring Tool for Imparting Flexibility to String of Pole Tools, whilst allowing Positive Rotation of the Bit and Attached Under-reamer.

Fig. 64.—Russian Rig for Freefall Drilling.

over the casing mouth when the tools have been lowered, and this is retained in position until the tools are again withdrawn

DRIVE CLAMPS.

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1 " " " 3-in. "
1 Set spanners.

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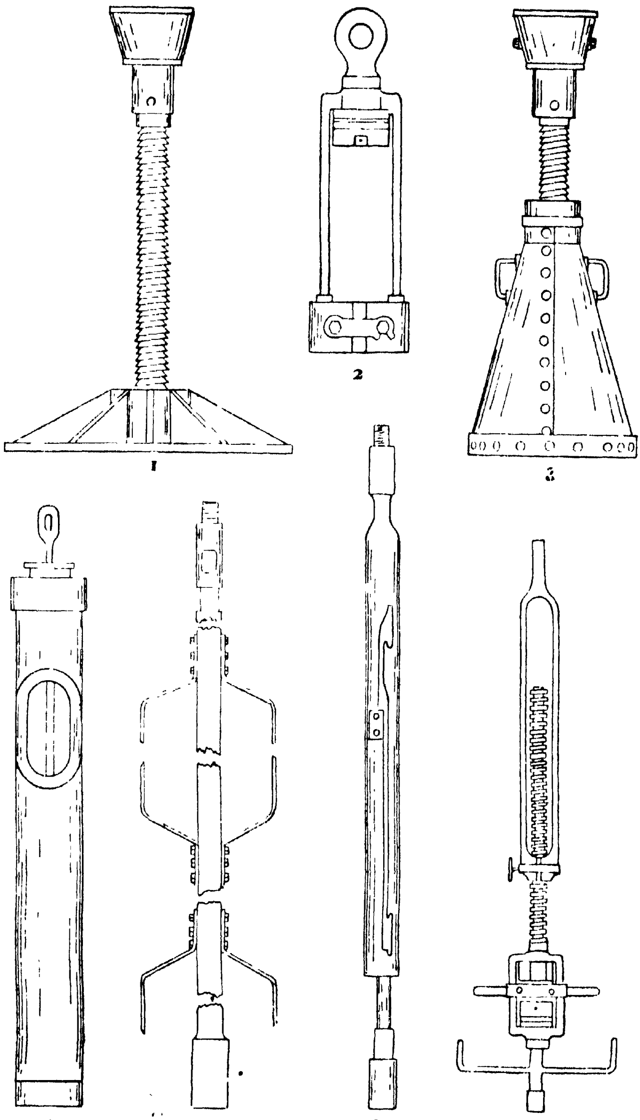
allowed to run loose when the sand pump or other cleaning tool is lowered into the well on a $\frac{5}{8}$ or $\frac{3}{4}$ in. wire rope. The bailers, sand pumps, etc., used for cleaning the debris are of the ordinary description, except that they are much larger. A form of spring freefall, illustrated in Fig. 64, has become increasingly popular during recent years. It rather takes the place of a rope in imparting flexibility to the reciprocating tools, whilst at the same time its attachment to rods enables a positive rotary action to be given to the suspended bit, so ensuring equal action of the under-reamer at all points. This action is uncertain in the case of rope drilling when the under-reamer and the bit are attached to the string of tools.

Heavy forged steel chisels or bits, often with side wings, are used, and the Russian form of under-reamer (see Fig. 56) is screwed to the chisel. It consists of a solid rectangular body machined to take two cutters pivoted at a central position by a strong pin. The two cutters are kept extended by a steel spring encircling the body externally, which forces upwards a cross bar connected to the cutters by two links. The cutters are so designed that they only expose the cutting edges when fully extended to a diameter about 2 in. larger than the casing through which the work is proceeding. When forced downwards against the spring the cutters pass tightly through the casing, the flat part only coming into contact with the sides of the casing, expanding out to their full width on emerging from the casing shoe.

In the Russian oil-fields the caving nature of the strata makes it necessary to keep the casing near the tools, consequently it is customary after each 5 or 6 ft. of drilling to rivet on a 4 ft. 8 in. length of casing, and lower it into position, never omitting at the same time to move the column up and down several times to keep it liberated. Heavy three and four fold pulley blocks suspended from timbers at the top of the derrick are used for this work of freeing the casing, and the wire rope is operated by one of the drums on the geared frame. If the tubes become too tight to be moved by the pulley blocks before they have been sunk 300-400 ft. below the preceding column, it is usual to make attempts to liberate them by using hydraulic jacks as well as the pulley blocks, a new column only being lowered when all reasonable measures have failed to free the preceding one.



1 2 3 4 5 6 7

Fig. 65.—Boring Requisites as Used in the Russian Oil-Fields.

1. Screw Jack for Pressing Casing.
2. Safety Hook for Raising Rods.
3. Jack for Raising Casing.
4. Sand Pump.
5. Sinker Bar with Guides.
6. Freefall.
7. Temper Screw.

Figs. 64 and 66 illustrate good types of boring machines used in the Baku oil-fields for drilling to depths of 2,500 ft. There are numerous modifications of geared frames in general use, but the actual speed of drilling does not vary much from an average of 5-6 ft. daily in wells of 2,000 ft. depth.

Rotary Flush Drills.—Considerable progress has been made during the last few years towards perfecting the rotary flush type of drill. The earlier varieties aiming at the extraction of a core have been discarded in favour of direct cutting or disintegration with suitably shaped bits. Many of the large supply houses now turn out a satisfactory type of drill, in which needlessly extravagant claims are often made for unimportant details of construction.

Rotary flush drills were first successfully used in Louisiana and Texas, where it was necessary to pierce thick beds of "running" sands which had defied all efforts with percussion drills. They have proved especially efficacious for negotiating heavy caving or swelling clays through which it was often difficult to drill with a percussion bit, and still more difficult to carry a string of pipe to any considerable depth.

The main feature of all rotary flush drills is a rotating table driven by gearing or driving chain from "*drawworks*" erected on one side of the derrick. The rotary table of one good rig consists of a massive hollow cast-iron block, on which are mounted four rollers, called grip rings, controlled by powerful screws, which enable the drill stem to be firmly grasped when inserted between them, without impeding its vertical movement. This table reclines upon a disc running on rollers or balls, and is rotated by bevel gearing engaging with teeth cast on its lower outer edge. The upper table is attached to the rotary disc by heavy steel studs over which it is slipped. The driving shaft at the side of the rotary is provided with a clutch to throw the table in and out of gear at will.

One modern rotary table is furnished with an appliance for screwing up the stem by power instead of by hand as is usual.

The hoisting gear or drawworks consists of a main shaft with chain transmission from the engine, and this shaft drives the table and also a second shaft—upon which the hoisting drum is keyed—for manipulating the pulley blocks from which the drill rods are suspended. When the rotary is running, the drum lies idle on the

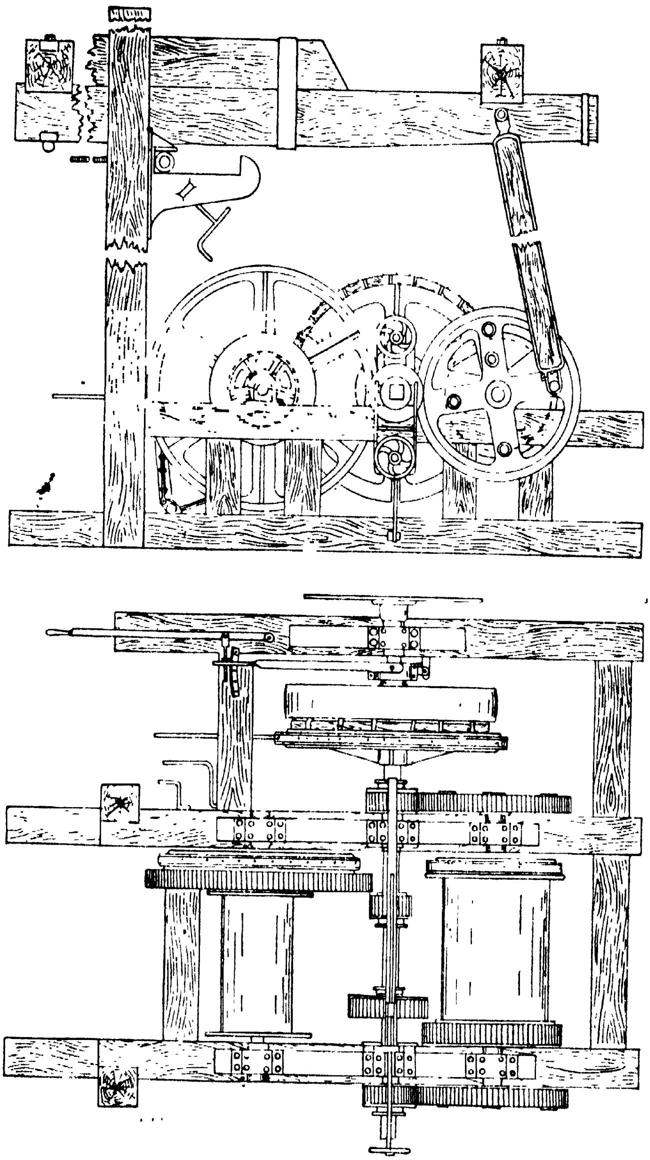


Fig. 66.—A Common Type of Russian Boring Frame.

second shaft, but it is controlled by a powerful brake and can be thrown into action by a clutch placed immediately below the steam regulation wheel, and handy for control by the operator.

The modern drawworks are very strong, and mounted upon steel girder section framework that ensures rigidity. A heavy travelling block suspended from the casing pulleys in the derrick crown supports the drill stem, the wire casing line being attached to the hoisting drum at one end, and the shackle of the travelling block at the other. A strong hydraulic swivel head attachment with flexible hose connections from circulating pumps, and with powerful supporting hook, is slung from the travelling pulley block, enabling a flush to be maintained through the drill rods whilst rotating and descending.

On later designs several improvements have been introduced. A square or octagonal hollow stem is used as the upper length of drill pipe, thus saving the tubes which always become badly scored and damaged by the grip rings. The positive action thus imparted to the drill rods is not without its dangers, as the old roller and grip device really acted as a safety appliance, the drill rods resisting torsion if a heavy strain were applied, and the tubes simply became badly scored by the slipping rollers. A belt, or clutch, or something should be introduced to throw the table out of gear if the bit is gripped.

A special length of drill rod is provided for attaching to the rotary swivel, and passing through the rotary grip rings. This joint is 24 ft. long, instead of the usual 20 ft., and is constructed of ½-in. thick metal. The advantage of this joint is that when the operator has drilled down to the swivel, and wants to insert another length, he pulls the 24-ft. drill rod, and suspends the column of drill pipe on the slide tongs by the collar of the first 20-ft. joint. At this stage the bit is 24 ft. above the bottom of the hole. He next stands the drill joint and swivel up in the derrick while he attaches the next 20-ft. joint to the column resting on the slide tongs. When this connection is made the column is lifted up by the elevators on the collar of the new joint, the slide tongs removed from the lower collar, and the whole column lowered 20 ft., when the elevators again rest on the slide tongs. The bit is now 4 ft. up from bottom. The 24-ft. drill rod and swivel are

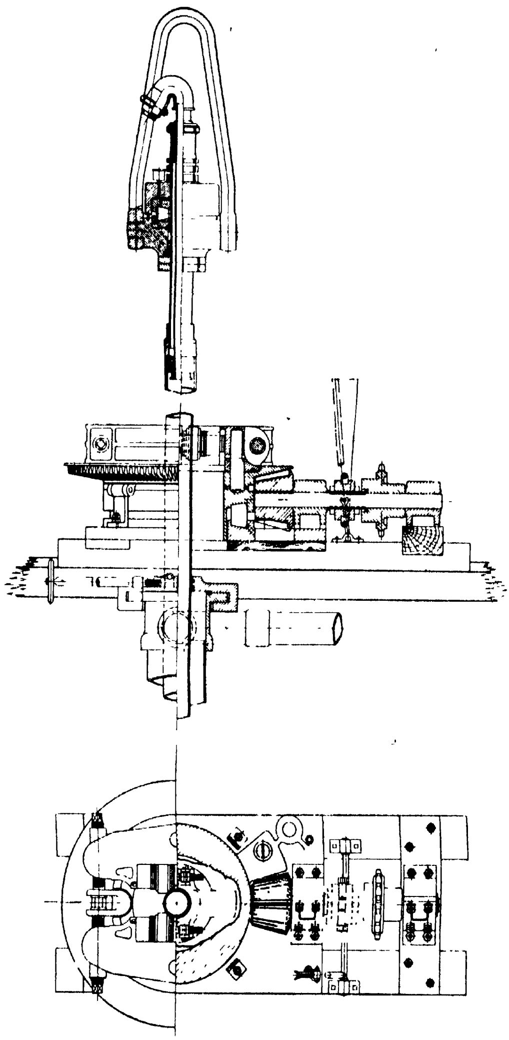


Fig. 67.—Hydraulic Rotary Table and Hydraulic Swivel, showing a Blow out Preventer beneath Table.

then attached, after which the column is again picked up by the swivel and the collar lowered below the rotary table. The grip rings are then set up to the drill rod, the pump started, and as

soon as a thorough circulation of mud is obtained the pinion clutch is thrown in and drilling started. The advantage of the extra 4 ft. on the drill joint is to enable the operator to drill the new length down without stopping; if it were only 20 ft., he would have to stop the rotary and open the grip rings to allow the collar to pass through the rings.

On one new plant double brakes were introduced acting singly or jointly, and two gears were provided for varying speeds.

Two duplex pumps of a capacity of about 200 gals. per minute at 150-200 lbs. pressure per square inch are securely bolted to the floor at one side of the derrick or on a small outside platform. The delivery mains are equipped with valves so that either pump at will can be made to deliver into the drill stem, and so maintain circulation in the event of one pump breaking down. In order to reduce the quantity of flexible hose uniting the pump with the hydraulic swivel, the delivery pipe is led about 20 ft. up the derrick. When negotiating particularly soft material it is good practice to extend the length of both the delivery pipes from the pumps and the hose connecting to the swivel, thereby enabling the driller to insert two joints of drill stem instead of one, and so reduce the length of time occupied in making connections by 50 per cent. New joints about to be inserted must be connected on the ground, and the swivel attached ready for hauling and insertion before the circulation is stopped preparatory to breaking the joint.

The introduction of an improved mud pump is much needed. The plungers and valves become cut up in a surprisingly short time, necessitating constant repairs, and making it essential to have a large number of spare valves and cylinder liners always on hand if delays are to be avoided.

Derricks used for rotary drilling have been increased to a height of 100 and even 120 ft. to enable the withdrawal of drill pipe in lengths of 60-80 ft. when replacing a bit or withdrawing the pipe for any purpose.

The drill stem consists of special heavy *iron* tubing with coarse tapered threads to withstand frequent unscrewing and facilitate rapidity of manipulation. Sometimes square-threaded rods are used, and in modern plants for deep drilling it has become the custom to have every third or fourth joint a normal tool joint with

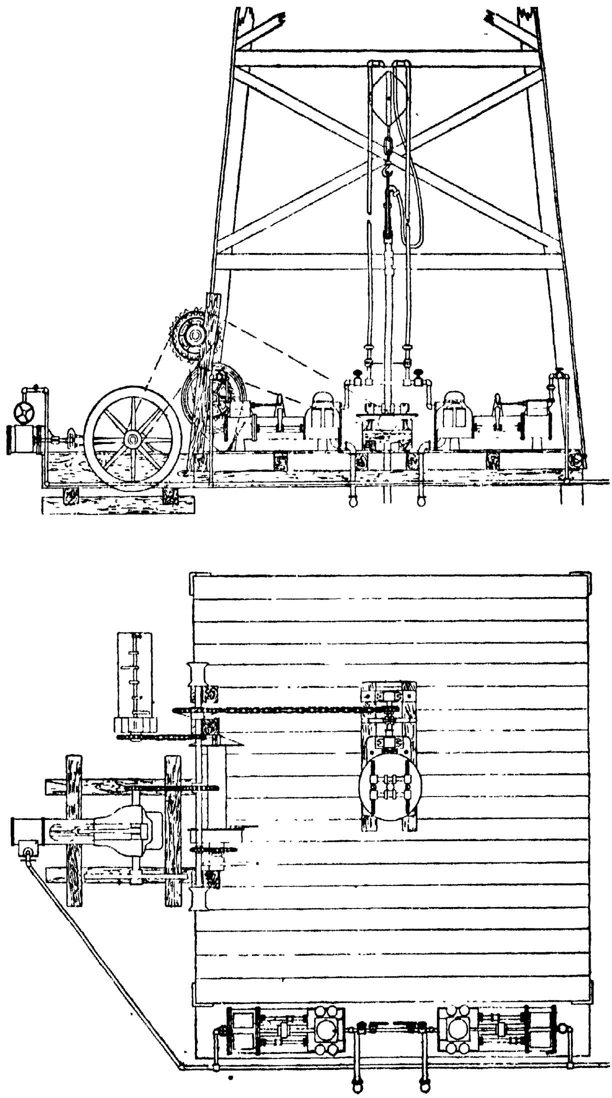


Fig. 68 - Rotary Flush Type of Drilling Rig.

(Enlarged View of Fig. 67.)

taper threads for screwing up. This kind of joint is more easily broken and made up and stands considerably more wear.

Rotary flush drilling bits are generally of the fish-tail type with the wings set off slightly to present a cutting edge to the body against which they are pressed. The flushing fluid emerges in jets at a high velocity from two holes placed just above the wings and strikes vertically downwards towards the cutting edge. Some designs of bits have three or four wings, thus obliterating the fish-tail character, but facilitating the formation of a round hole where side boulders or unequally hard strata tend to produce a flattened hole.

A good practice is to have an emergency pit of very heavy mud ready connected up to the pumps, then, if the well comes in with a big gas pressure, a blow-out preventer (described hereafter) will hold it under control while the light circulating fluid is being replaced by the heavier mud from the reserve pit. The blow-out preventer may then be released and casing inserted, after which the heavy mud is washed out and the water bailed out. The well then comes in without trouble.

No special precautions are usually taken to prepare a mud mixture, the importance of which is often greatly overrated. In most cases the circulating fluid keeps the finer material in suspension, and this constitutes the solution used for drilling. The sump from which the pumps draw their water or circulating mud is kept fairly clean by leading the return fluid along a nearly horizontal channel or duct in which heavier sediment may settle before being allowed to enter the sump hole. The heavy mud is periodically removed from the bottom of the ditch.

The operation of a rotary calls for no special skill. As the drill clears itself it is allowed to descend by relaxing the brake on the hoisting drum. The attachment of a new joint must be hastily made when the pump is shut off for a few minutes, and sometimes it may be necessary to violently jerk the rods a few times to unclog the jet holes and restart circulation. If the pump fails through any cause during operation the rods are raised a few feet, the other pump started up and circulation restarted.

Modern practice has called for the employment of heavier and larger drill rods, and 6-in. heavy tubing weighing 29 lbs. per foot

is now commonly used. Besides imparting greater torsional strength for transmission of power they reduce the annular space between the well sides and drill rods, thus increasing the velocity of the circulating fluid. Friction naturally fixes limitations to the reduction of area, but it is obvious that the higher the velocity of the liquid the sooner will particles of dislodged material reach the surface.

Two important but little appreciated factors in flush drilling, bearing on successful work, are worthy of attention.[1] Firstly, it is a mistake to continue circulation of mud when not rotating, and the bit is off the bottom, for there is a tendency in soft strata to form a flat hole through the jets impinging at two spots on opposite sides of the drill. Secondly, the drill stem, when left stationary, certainly leans against the wall of the well at places, thereby deflecting the circulating mud to the opposite side, and tending to enlarge the hole at those points.

Porous sand and gravel saturated with water can often be pierced with the rotary when all other methods have failed. A thick mud is prepared by puddling clay, and continuous pumping gradually "muds up" the stratum, and usually enables the troublesome bed to be passed. Sometimes the whole of the circulating fluid is absorbed for days before the sand or gravel is rendered impermeable and circulation established.

Puddling machines are sometimes employed for preparing a thick clay mixture where drilling furnishes insufficient clay to produce a satisfactory one. A clay free from sand must be selected, when a mixture will be introduced that will scarcely settle if left quite undisturbed.

The universal use of the rotary is not imminent yet, notwithstanding its extended use. The process as at present evolved does not readily admit of under-reaming, and sharp sandy seams only a few feet thick wear away the drill in a short time, necessitating its removal for dressing.

Under-reaming can be effected by a newly invented bit known as the Donald Eccentric Flush Bit, which is merely an adaptation of the eccentric drill to rotary work. If this proves applicable to

[1] See Discussion on "The Use of Mud-laden Water in Drilling Wells." I. N. Knappe, Amer. Inst. Min. Eng., February 1915.

all kinds of ground a great advance will have been made in rotary drilling. This is seen in Fig. 69.

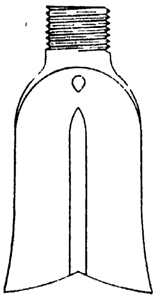
The simplest and most popular method of rotary flush drilling is to drill with a bit slightly larger than the collars of the casing it is intended to subsequently insert, and continue in an open hole till caving or heaving prevents further progress. Casing is then introduced and, if necessary, washed down to its seating, after which drilling proceeds with a bit which will freely pass through the casing.

This method can only be adopted where the strata hold up well for long distances and no water sources have to be excluded. When caving is prevalent it is necessary to let the casing follow near the bit, and under such circumstances it is apparent that a single hard stratum would check its further descent. Under-reamers have been used for passing bands of hard rock, but they are not favoured by rotary drillers and there are no really satisfactory types on the market.

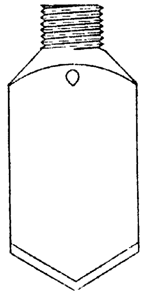
Where no hard beds are known to exist the casing can be provided with a fish-tail bit and employed as a drill stem. Unless the column can be safely removed and the bit replaced by an ordinary shoe it is then necessary to drive away the bit, or blow it off with some explosive, before a reduced column of tubes can be lowered, or drilling can be continued. Such work is risky in all but extremely favourable beds, as damage to the bit entails the entire withdrawal of the lining tubes.

One of the chief reasons for the restricted application of rotary drilling has been the difficulty of piercing hard bands, often inclined at an angle, which easily deflect the drill from the vertical. The Sharp & Hughes cone bit was the first, and is, perhaps, the most successful of a class made to overcome this trouble. Whilst having its limitations, it does enable rocks to be perforated which resist the action of fish-tail and similar chisel-shaped bits.

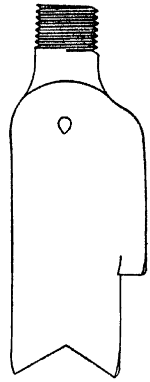
The principle on which these drills is based is one whereby the rock is crushed rather than cut away. One of these bits is designed with two cones pivoted on pins carried in a strong wrought-iron or steel framework. The apices of these two cones almost meet at the centre of the hole, thus by rotating the tool the cones rotate on their own axes due to the friction between



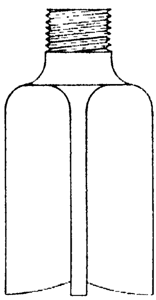
Fish-tail.



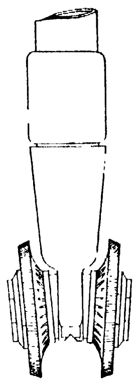
Diamond.

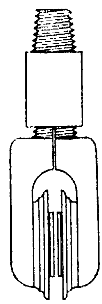


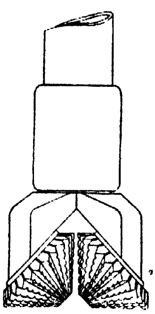
Donald
(Under-reaming
Excentric Flush.



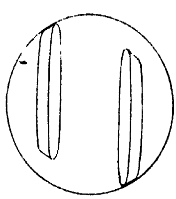
Star.



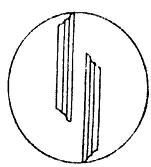




Sharp-Hughes
Cone.



Sharp-Hughes
Disc.



Oil-Well Supply
Disc.

Fig. 69.—Rotary Drilling Bits.

them and the bottom of the hole. In order to obtain a crushing effect the surface of the cone is grooved both vertically and laterally, thus forming a number of short blunt points which break the cohesion of the rock under great pressure, causing it to crumble away. Special arrangements are made for lubricating the pins which form the axes of the cones, and also to prevent the tool becoming clogged by the flushing fluid, or by the debris caused by the crushed rock.

A newer type which first attracted notice in California and has come quickly to the front is the rotary "disc bit." In place of the cones, previously mentioned, tempered steel or chilled cast-iron discs are employed, the cutting edge being tapered off to an edge or dished to present a cutting edge to the stratum in which it is pressed. These discs rotate freely on pins attached to the body of the tool, and in order to obtain the cutting or crushing effect the pins carrying the discs are fitted one on either side of the centre instead of radially, by means of which the whole of the bottom of the hole is operated upon by the cutting edges of the discs. Progress is of necessity slow compared with the speeds obtained when negotiating softer strata, and the wear and tear on the tools is very heavy. The lengthy and expensive nature of repairs to bits is drawing attention to the feasibility of using chilled cast iron for their construction, so that a worn-out bit may be discarded and replaced by a new one.

Fishing tools must be provided with rotary plants. The nature of the process restricts the class of accidents to a few for which provision is simple and inexpensive. By far the most common accident is a broken or stripped drill stem, known to drillers as a twist off, which can be recovered by lowering either an "*overshot*" or a "*spear*"; the former taking an outside grip, the latter an inside grip of the tubing.

The "overshot" is simply a length of tubing provided with a bell guide which will freely pass over the drill stem, and fitted with spring clips that will catch beneath the first collar they pass. If desired it can be designed to grip the tubing at any point when raised or jarred upwards, and this latter type can be so designed with a hinged dog that it can be released by pulling and hard jarring if the tubing fails to respond to reasonable application of force.

Rotary fishing spears may be of a very simple design if the drill rods are quite free, but if they are gripped by accumulated detritus, spears of the ordinary type used for casing are employed, with internal hollow spindle through which the flushing can be continued during the process of lowering on drill pipes and setting.

Another useful type of fishing tool is the die and tap, which can be lowered with guides to screw a thread either internally or externally on stripped rod ends or sockets, or even fractured ends of tubing.

Tool joints for rotary drill pipe are often internally screwed on the female end, especially when used in holes where there is a narrow margin between the outside diameter of drill pipe collars and the casing or bore hole. This enables the simple, rapid, and firm attachment of flush pipes if a drill rod breaks, and the re-establishment of a circulation of mud if necessary.

The loss of a steel bit of the short type is often a matter of concern, as its position prevents its capture by fishing tools. In soft ground bits can be driven aside by percussion drills or even other strong flat bits, but if this is impossible cement should be inserted after washing the well clean, and the lost bit can then be cut out by a chilled shot rotary cutter. Rotary drillers are now favouring bits several feet long, or bits with long drill collars, so that in case of loss they stand up vertically and can be more easily recovered. The disadvantage of a long fish-tail bit is that the jets of fluid are too far from the cutting edges of the bit.

An apparatus which is largely employed with rotaries is what is called a "*Blow-out Preventer.*" These are massive cast-iron fittings, attached to the last column of casing inserted, which enable adjustable iron slips that encircle the casing to be closed tightly around the drill stem, in case the well commences to flow whilst drilling is in progress. When closed the oil, gas, and circulating water discharge from a side orifice that can be controlled by a valve, and can be led through piping to a point distant from the well whilst the oil sand is being drilled into. The full specification of a rotary outfit is as follows:—

Specification of 20-in. Rotary Drilling Rig and Accessories for 2,000 Feet Holes.

Boiler.

1 Steam boiler capable of evaporating with ease 2,500 lbs. of steam per hour at 100 lbs. pressure with fuel found in the district, fitted with feed pump, injector, and spares.

Engine.

1 11 × 12-in. 25 H.P. oil-well drilling engine, fitted with sprocket wheel, special 50-in. balance wheel, and 1 extra rim. No pump or heater required. British standard screwing steam and exhaust.
1 Plate and tie bolts for engine.

Derrick.

1 Derrick, 106 ft. high.

Machine.

1 20-in. rotary, complete with wrenches.
1 Extra heavy pattern hoisting drum, complete with shaft, clutch sprocket wheel, drum clutch, drum lever, bearing boxes, collars and set screws, drum brake and brake lever, wood-lined brake bands.
1 Extra heavy pattern line shaft, complete with engine sprocket wheel, rotary sprocket wheel, drum sprocket wheel, bearing boxes, collars and set screws, two cat-heads, and fitted for three-post outfit.
2 Extra heavy extra steel posts, with all necessary bolts and irons for setting up drum and line shaft (fitted to derrick).
2 3 × 12-in. 24-ft. head boards.

Swivels.

2 4-in. improved loose bail hydraulic swivels, complete with spanner wrenches. Connection to 6-in. drill stem.
2 Pieces of 2½-in. six-ply rotary drilling hose, each piece 30 ft. long. Hose to be of special quality, and armoured both inside and outside.
2 Sets of 2½-in. rotary hose clamps and couplings (4 nozzles and 4 clamps).
1 Piece 1-in. four-ply derrick hose with couplings, 25 ft. long.

Crown Block and Pulleys.

5 Crown pulleys, 20 in. dia., fitted with steel shaft, and made for wire lines.
1 Heavy structural steel, 8 in., 1 beam crown blocks, with closed bearings.
1 Extra heavy triple steel travelling block, 37-in. shell, bronze-bushed and self-lubricating.
1 ⅞-in. × 800 ft. wire drilling line (patent flattened strand).
1 ⅜-in. × 2,500 ft. wire sand line.
1 5-in. double swivel hook.
1 10 lb. S.R. hook for cat-head line.
1 Heavy 3½-in. strapped "C" hook.

1 $1\frac{1}{4}$-in. strapped "C" hook.
1 Set forgings, shafts, sprocket wheel, gear wheels, and boxes for mud mixer.
1 4 and 6 in. bailer top and bottom.
2 4 and 6 in. back pressure valves.
Necessary strainer.
2 4 to 8 × 10-in. D.W. packers.
1 4 to 10 × 13-in. ,,

Tongs and Elevators.

1 Set of 4-in. slide tongs, extra heavy.
1 ,, 6-in. ,, ,,
1 ,, 8-in. ,, ,,
1 ,, 10-in. ,, ,,
1 ,, 4-in. Mann Fair's extra heavy wrought iron elevators.
1 ,, 6-in. ,, ,, ,, ,,
1 ,, 8-in. ,, ,, ,, ,,
1 ,, 10-in. ,, ,, ,, ,,
2 Pairs No. 12 Vulcan flat chain pipe tongs and 1 spare chain.
2 ,, $13\frac{1}{2}$,, ,, ,, ,,
2 ,, 14 ,, ,, ,, ,,
2 ,, 15 ,, ,, ,, ,,
1 Only Californian chain tongs, flat chain, 4-in., 6-in., 8-in., 10-in. jaws.

Bushings.

2 6 × 4-in. forged steel pipe bushings.
2 8 × 4-in. cast-steel pipe bushings.
2 10 × 4-in. ,, ,,
2 $6\frac{5}{8}$ × 4-in. ,, ,,
1 6-in. forged steel drilling coupling, extra long.
1 4-in. ,, ,, ,, 16 in.
1 6 × 4-in. ,, ,, ,, 14 in.
1 Manilla cat-head line, $1\frac{1}{4}$ in. × 225 ft.
6 $\frac{7}{8}$-in. wire rope clips.

Sprocket.

80 ft. No. 103 J.D. malleable sprocket chain.

Chains.

30 ft. steel sprocket chain No. 2,060.
10 ft. No. 2,480 chain.

Drills.

3 12-in. rotary drills, 6-in. shank.
6 10-in. ,, 4-in. ,,
6 8-in. ,, 4-in. ,,

Blow-out Preventer.

1 Blow-out preventer, with 4 and 6 in. slips for drill stem, and two sizes pipe flanges 10 × 8 in., with 5-in. outlets.
2 6-in. extra flanges.
2 6-in. iron body gate valves for closing overflow of preventer.
4 Joints of 6-in. pipe for discharge.

DRILL STEM.

2,000 ft. × 4-in. iron rotary drill stem, 15 lbs. per ft. All threads to be well protected.
2,000 ft. × 6-in. iron rotary drill stem, 29 lbs. per ft.

FISHING TOOLS.

1	Rotary trip spear for		$12\frac{5}{8}$-in. drive pipe.	
1	"	"	10-in.	"
1	"	"	8 in.	"
1	"	"	$6\frac{5}{8}$-in. casing.	
1	"	"	4-in. drill pipe.	
1	"	"	6 in.	"

1	M. & F. case-hardened forged steel die nipple for				$12\frac{5}{8}$-in. drive pipe.	
1	"	"	"	"	10-in.	"
1	"	"	"	"	8-in.	"
1	"	"	"	"	$6\frac{5}{8}$-in. casing.	
1	"	"	"	"	4-in. drill pipe.	
1	"	"	"	"	6-in.	"

PUMPS AND CONNECTIONS.

2 10 × 6 × 12-in. pumps.
Full equipment of connections for same.
Equipment of spares.

HAND TOOLS, ETC., FOR USE OF DRILLERS.

Usual equipment per rig.

Much hostile criticism has been directed by oil operators towards rotary flush drilling. It is clear that in new territory, where the depths of oil sands or water-bearing formations are unknown, its use may be attended by grave risks. It is exceedingly difficult to judge the importance of manifestations of oil, and the author has heard quite opposite views expressed by two experienced drillers concerning the indications in the same well. An oil sand washed by water is often white or grey, and displays no feature to attract attention, so that unless oil films appear or gas is freely evolved with the circulating fluid the identity of the sand is concealed, and an oil sand may be passed unobserved.

Drillers engaged for years in a particular field can instinctively estimate the value of "shows" in that district, but the application of this knowledge to a new area, where conditions are quite different, would be very misleading. The same arguments apply to an appreciation of the nature of the strata in which drilling is proceeding. Besides a knowledge of when hard and soft beds are

being penetrated, the only available information is imparted by a few particles that reach the surface with the flushing mud. The thick mud disguises any change of colour, and the long interval elapsing before a heavy particle of detached rock reaches the surface, compared with a particle of clay or fine sand, makes it difficult to assign to it a correct depth. In fact one naturally assumes that any hard fragments which collect in a receptacle placed beneath the return flush are derived from the last hard seam noticed by the rate of progress. Information is, in fact, mainly confined to a knowledge of hard and soft beds, with perhaps supplementary data when sands or sandy shales are struck.

Flush drilling is most successful in regions where the approximate depths of the oil-bearing and water-impregnated beds are known.

The following example, illustrative of the subject under consideration, taken from a paper by I. N. Knappe, will explain the danger of flush drilling:—

"One of the several visits I have made to the Texas oil-fields was in October 1901, and on that occasion I saw a well on the Hogg-Swayne tract of Spindle Top that had been drilled into the known oil horizon by the hydraulic rotary method, but made no showing of oil, notwithstanding that within a radius of 250 ft. around it were a number of gushers, and the original pressure of Spindle Top wells had been reduced but little. After this well had been agitated and bailed for six days, it finally gushed and flowed a solid 6-in. stream of oil until shut in. If this had been a prospect well in a new district, where the oil horizon had not been definitely located, there evidently would have been a strong possibility of passing the oil stratum without revealing its productive capacity."

Many European operators have strongly opposed the introduction of flush drills, and stoutly affirm that oil sources have become flooded and productive wells injured in the neighbourhood of flush drilling. The advocates of flushing systems maintain that the ill-effects have been exaggerated, and declare that the success of the process depends upon the return of most of the flush water used. They also contend that porous seams can be "mudded" up, and emphatically deny the accusations of opponents. A

middle course should be steered. Petroleum producers cannot afford to neglect the claims of a drill which will often accelerate the drilling rate by several hundred per cent. If the necessity of excluding water at known points is appreciated, and wells are sunk sufficiently far from development to avoid the possibility of water entering and flooding partially exhausted oil sands, flush drilling can be safely employed. It would be folly to drill with mud amidst a group of wells drawing from a succession of oil sands, as the water would certainly find its way to points of abstraction, but in undisturbed ground, where the porous beds are all saturated with water or oil and can admit no more fluid, there is little danger.

Fauck "Rapid" System.—Percussion and hydraulic drilling principles are combined in the Fauck system, which has been employed with some success in the Carpathian oil-fields. Unique features are introduced in the rapid delivery of a succession of short-stroke blows by means of an eccentric, instead of the customary walking beams. Mechanical features of the plant have been carefully worked out to resist the vibration naturally occasioned by blows at a rate of 100-150 per minute, the stroke, however, being not more than 3-6 in.

The chain from which the drilling tools are suspended over the mouth of the well is led over a series of pulleys to a drum, from which it can be fed out by worm gearing, but in its course it partially encircles the eccentric, which imparts to it the movement that is transmitted to the tools. From the main driving shaft, motion is conveyed to a second shaft, to which a drum is affixed for bailing or other purposes, powerful side brakes providing means of control. The hoisting drum can be brought into action by a jockey pulley that engages with a belt running loosely on flanged pulleys keyed to and constituting part of the drums.

Ordinary ground is negotiated by means of short, chisel-shaped bits, through which a jet of water is expelled through the solid drawn boring rods that extend to the surface. At other times the return flush is put in operation, whereby water or mud is delivered into the bore hole outside the drill rods, and returned to the surface through the interior of the rods. This procedure is effected by the attachment of a special casing head and the employment of annular cutters. Simultaneously with the reciprocating

movement, the tools are turned by hand, and this being permitted by the introduction of a polished hollow rod that passes freely in a packed gland at the surface, small cores of strata are raised by the rapidly ascending water in the drill rods, and ejected, when the formation is sufficiently hard to resist complete disintegration.

A diminished number of blows per unit of time may be accompanied by a corresponding increased length of stroke, the extent of such variation being decided by working conditions.

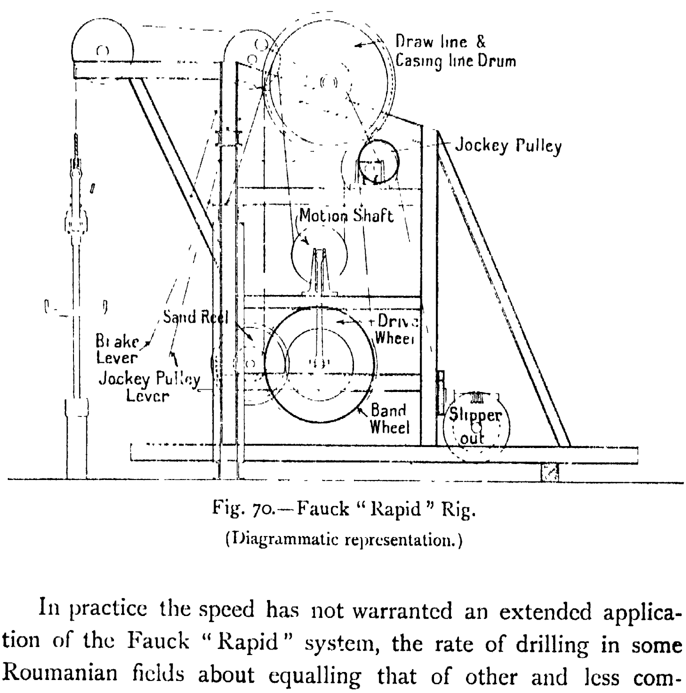


Fig. 70.—Fauck "Rapid" Rig.
(Diagrammatic representation.)

In practice the speed has not warranted an extended application of the Fauck "Rapid" system, the rate of drilling in some Roumanian fields about equalling that of other and less complicated systems.

This system may also be employed without a flush, when the length of stroke is increased, with a corresponding decrease in the number of blows.

Fishing Operations and Appliances.—The recovery from bore holes of lost tools often demands great skill both in the design of suitable appliances, and in their manipulation. Accidents may be divided into two classes, viz.:—

(*a*) Those due to a simple fracture or severance of the rods, rope, or some part of the string of tools where there are no contributory difficulties.

(*b*) Those where complications ensue, such as are occasioned by the falling of the whole or part of the tools when being lowered or raised, collapses of casing, or inrush of sand or debris on the tools before they can be raised.

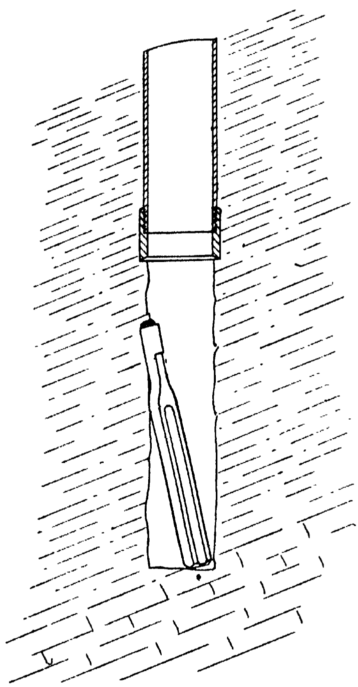


Fig. 71.—Lost Bit.

Shows how recovery is complicated when the bit is driven to one side beneath the casing.

The former class of accidents are usually not difficult to deal with, the latter may entail weeks, months, or even years of tedious, patient work, especially when the lost object is reclining in an inclined position in soft ground beneath the shoe of the lining tubes, as in Fig. 71.

There are two distinct types of fishing tools: those lowered and operated by a rope, and those lowered and manipulated by a string of heavy tubes or rods. Rope fishing tools rely upon the use of long-stroke jars for releasing objects that resist withdrawal. Rod tools enable force to be applied by jacks as well as jars if necessary, and also other positive motions to be applied.

American percussion drillers favour or cling to the rope tools, whilst British and European operators prefer the more positive methods of fishing with fishing rods or tubes.

Fishing tools may also be subdivided into those which can be released at will after a grip has been established, and those which cannot be made to relinquish their hold after attachment to a lost

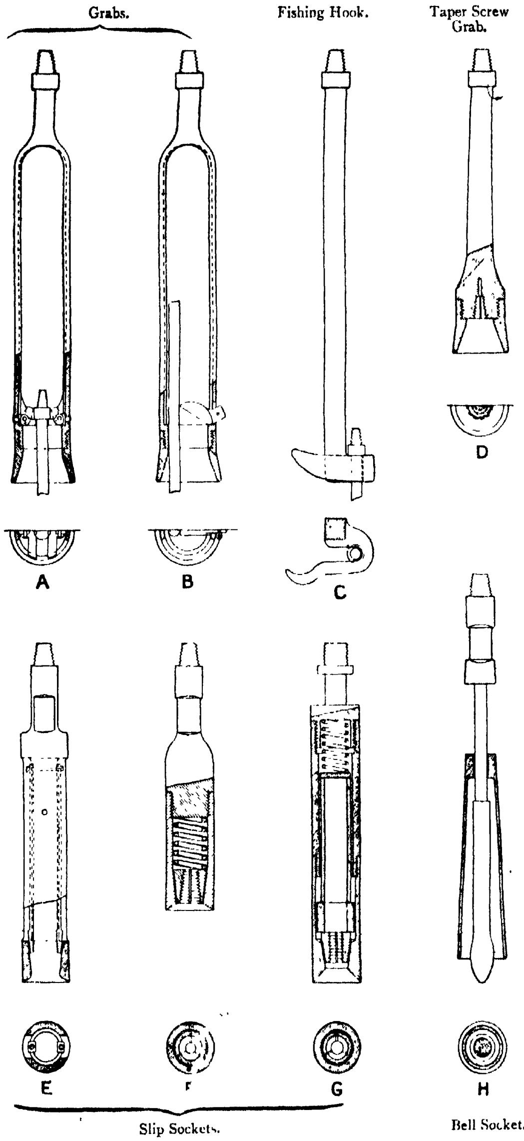


Fig. 72.—Fishing Tools.

object. The use of the latter, it will be understood, may often be attended with grave risk.

Fractured or unscrewed boring rods may be recovered by one of the tools shown in Fig. 72. Provision is usually made on tools of this type for a bonnet which will fit the casing and ensure its passage over the end of the lost object.

When the rods or tools have sustained damage, or for some other reason their release is likely to be difficult, a more scientific tool is used, such as a slip socket.

Fig. 72, E, shows an inexpensive, popular American type of slip socket for use with a cable. The slips are kept extended by a strip of wood whilst lowering. When the bowl passes over the object to be caught the wood is knocked away and the slips fall into the taper slots provided for their reception, and grip the encircled tool. A few upward taps with the jars produce a firm hold, after which the rope may be attached to the beam and repeated blows administered till the instrument is freed. By jarring downwards the hold may be relaxed and the tool possibly freed, but there is some uncertainty about this.

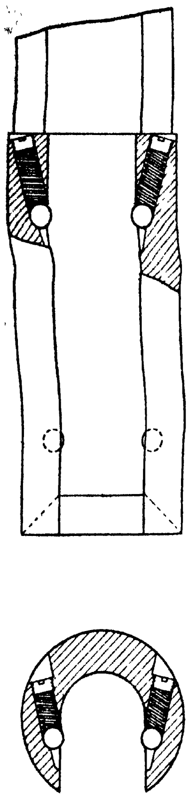


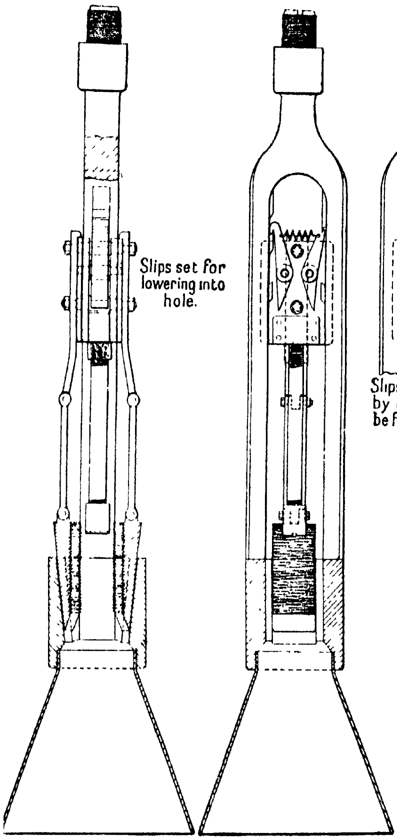
Fig. 73.
Ball Slip Socket.

Another variety of American slip socket is shown in Fig. 72, F and G. In this the slips must be prepared to closely approximate in size the lost object, as its latitude is small. A bowl is attached, if necessary, to guide the socket over the lost tool, which forces up the slips against a spring until it enters. On applying tension to the rope a hold is established that increases with the power applied.

An American tool of ingenious design, suitable for recovering broken round drilling rods, is shown in Fig. 73, where steel balls travelling in tapered-milled passages grip any object which is thrust between them on the fishing tool being raised.

All the above tools lack means of releasing the grip of an object

if it fails to respond to the application of power. A fine slip socket representing one of a type of Russian design, which possesses all the advantages of those described, but can be released at will, is



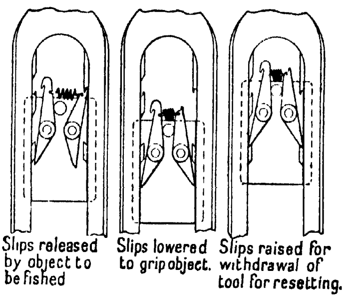


Fig. 74.—Russian Slip Socket.
(Type that can be released.)

On lowering instrument upon lost object, the internal spindle is pushed upwards as far as permitted by the right hand catch (*a*) thereby releasing the spring catch on the left which allows the slips to fall (*b*) into the cone and grip the lost object between them. To release hold of object, if it cannot be raised, the tool is jarred downwards, forcing the spindle and catches to position (*c*) where their lower extremities lodge in a recess and support the slips out of contact with the lost object.

shown in Fig. 74. It is usually used on fishing poles, thus enabling great power to be applied.

Fig. 75 illustrates a set of fishing tongs designed to extract small lost objects.

Cable tools which have become jammed to such an extent that ordinary jarring will not effect their release must be disconnected from the cable before fishing tools can be used. Cables are severed

just above the rope socket by a knife. The tool slides over the taut rope as it is lowered on a light string of rods or a rope with jars. On striking the tools the knife blade trips, thereby bringing the edge against the rope on drawing upwards, after which jarring is continued till the rope parts.

Broken or dropped cables are recovered by rope grabs or spears, such as those shown in Fig. 76, lowered on rope or rods

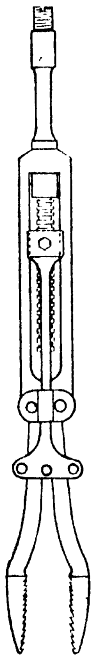


Fig. 75.
Fishing Tongs for Raising Small Lost Objects.

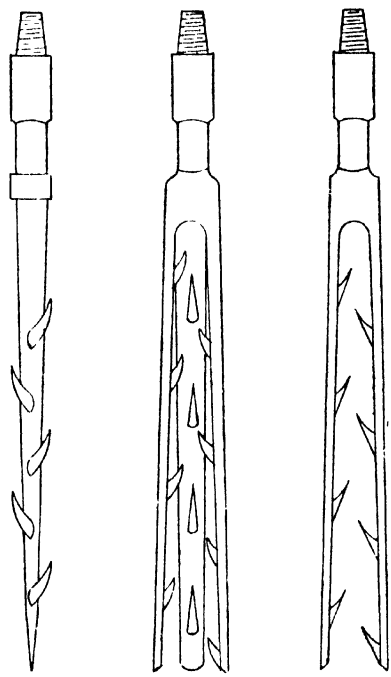
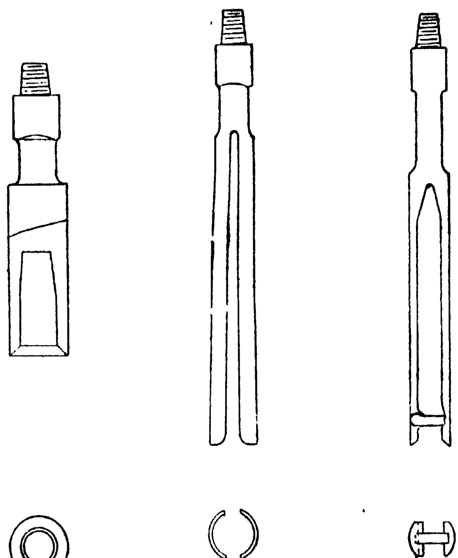


Fig. 76.—Rope Spears and Grabs.

with or without jars. The tangled rope becomes entwined with the prongs of the fork falling or driven into the mass, when the rope and tools may be raised. If the tools have been dropped in the hole, or the breakage of the rope has been due to the sticking of the tools, it may be impossible to withdraw the tools even by jarring. Under such circumstances it is usual to continue jarring until the rope breaks. If this occurs above the junction with the

tool the operation is repeated, but the weakest spot is usually at the socket, where the rope has sustained most damage through buckling.

Bailers lost through the breakage of the sand line or sticking of the bailer may be treated in the same way, but bailers may often be released without cutting the line, by lowering on light rods such a tool as Fig. 77, C, and then jarring or jacking up.



A B C

Fig. 77.—Fishing Tools.

Drive Down Socket. Socket for taking Friction Hold of Lost Objects. Sand Pump Grab.

Another effective American tool which will recover light bailers from which the hook has been dragged is the Mandrel or Bell socket (Fig. 72, H).

The outer tapered piece slides freely on the upper part of the central mandrel. When lowering, if necessary with a bell guide to direct it in upon the bailer, the taper socket rests on the collar, but on reaching the object the socket slides up the mandrel and can

then be driven over the casing by blows from the collar. When the bailer top is driven well inside the taper piece the tool is raised and the enlarged part of the mandrel jambs the bailer between itself and the taper piece.

Specially difficult cases of lost tools in a confined space are occasionally overcome by lowering on rods, or tubing, milling cutters, or drills, and rotating from the surface to remove a burr, cut an end, or drill a hole which could be screwed or tapped and a firm hold taken on which to apply power.

A special screw jack, with ball-bearings and hollow screw for delicately feeding the tool whilst being rotated by a pulley, is manufactured for this purpose.

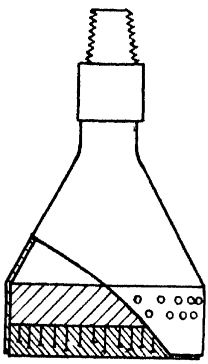


Fig. 78.—Impression Block.

Many of the worst fishing scrapes occur when the tools are lost in an unlined hole of soft strata. The lost part in su cases is rarely left standing vertically, a after the fracture or unscrewing of a joint un- affected part of the string of tools ma trike the detached part many times, and ause damage, or drive it aside before th ig is brought to a standstill. When dou xists as to the true state of affairs in t well, an impression block is sometimes ered to ascertain the position of the l ools. Impression blocks (Fig. 78) consist of wooden blocks mo d on a body suitable for lowering on rods or ropes into the Its lower flat or circular face, as the case may be, is covere ith a thick layer of some plastic material that will receive a retain an impression, the material being held to the wood by ils and wiring.

An exceedingly ingenious device for photographing lost objects was invented by a Russian engineer. Carefully fitted inside an hermetically sealed cylinder is a clockwork arrangement that, at a prearranged time, allows the discharge of compressed air into a hood below the apparatus that encircles or covers the lost object, then simultaneously switches on an electric light and opens the shutter of a stereoscopic camera. After a prolonged exposure the

instrument is raised and the plate developed. The apparatus is in reality more ingenious than useful, as objects rarely recline in a position that admits of photographing.

If the top of the lost tool be found to be lying to one side of the hole and in such a position that no tool could encircle it, efforts must be made to force it into a vertical position by suitably constructed hooks, see Fig. 72, C. In cases where the tool will not retain its vertical position a few balls of clay dropped around may give the necessary support whilst fishing tools are being lowered. Where cavings may have collected round the bit a long side spud (Fig. 79) may effect release, or if sand is the cause a column of small tubes may be lowered and the sand be washed away by a powerful water flush. In extreme cases a column of tubes with serrated shoe and water flush may be rotated sufficiently over the lost tools to reduce resistance to a negligible or at least practicable amount. Inrushes of sand or clay sometimes firmly embed the string of tools in the casing, and where the casing is of small diameter there is little chance of washing or spudding free. The casing can in such cases often be raised entire with the embedded tools.

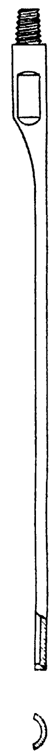


Fig. 79. Side Spud.

Fishing tools are frequently lost, and a second string occupied in effecting their recovery may also be lost. If, however, the recovery of the tools by fishing appears hopeless, it is usual to abandon the hole and withdraw as much casing as possible. In some cases it has been possible to wash the well free of clay and then pump in cement grout which encases the lost tool. Diamond or chilled shot drilling can then be used for extracting a core complete, in which the lost tools will be found, often lying diagonally across the core.

The apparatus needed for chilled shot drilling is not expensive or difficult to rig up in the event of an emergency. A drill crown can be constructed from a piece of heavy casing in which a slot or slots are cut, as in Fig. 80. This is attached to a length of casing to act as a core barrel, and the whole is coupled to a column of tubing or hollow rods that can be rotated at the surface by any

simple device. Steel grit is introduced into the flush water through a double cock, and this finds its way beneath the boring crown and grinds an annular space, the eroded material rising around the crown with the flushing water whilst the core mounts in the barrel. The core is broken and raised in the crown and barrel by pumping down some coarse material, as broken brick, which jams round the core and causes its separation when the tubes are raised.

Chilled shot and steel grit are produced by a secret process whereby a special mixture of cast-iron scrap and cast steel is allowed, in a molten state, to strike a jet of steam or compressed air that breaks up the falling mass as it falls into water.

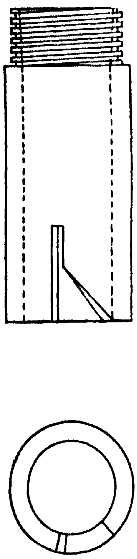


Fig. 80. Chilled Shot Crown.

Lost bailers are frequently chopped up instead of wasting much time on their extraction. Pieces of rock are thrown into the well, and drilling is proceeded with in the ordinary way by a somewhat sharper bit. The fragments of iron are raised in sand pumps with the other debris. A lost bit may be driven aside in very soft ground and passed without inconvenience, and the writer has known as much as 200 ft. of 8-in. casing driven aside in a soft stratum with little difficulty.

Occasionally detached objects absolutely disappear in a soft formation and are quite lost. The author can recall one instance where all traces of a fallen 20-in. casing spear were lost in an oil sand, although the well was subsequently deepened to another source. Cases are on record where seized tools have been fiercely ejected from the well during a flow of oil. Fig. 81 shows the state of a string of tubes expelled by gas and sand from a well where they were being employed to wash out an accumulated sand plug. In the Russian oil-fields heavy tools and 1,000 or more feet of $1\frac{1}{4}$-in. iron rods have been ejected in the same way, the rods coiling about the derrick in indescribable confusion.

Fishing Poles or Rods.—In regions where deep, expensive wells are the rule rather than the exception large operators provide themselves with fishing rods. The Russian type consists of from

2-4 in. diameter iron rods with parallel threading at one end and a collar at the other, a loose socket acting as coupling. A machined rib on the extremity of the screwed end fits into a cor-

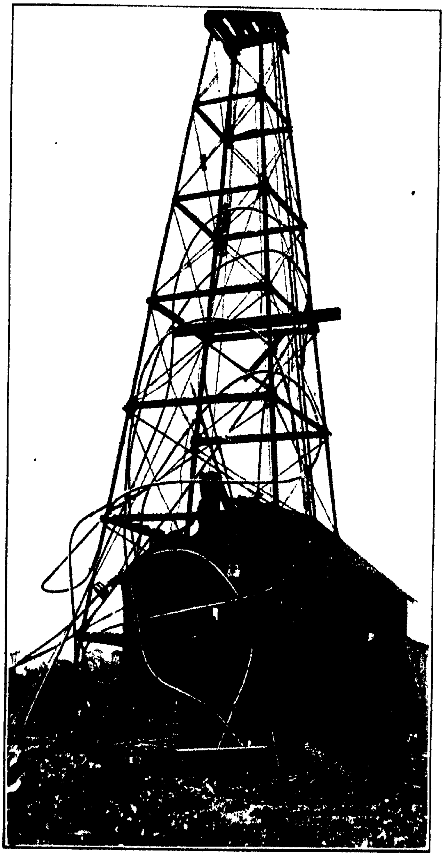


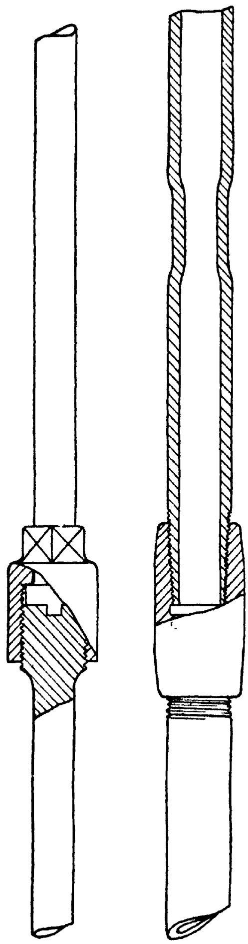
Fig. 81.- String of Wash Tubes Expelled by Eruption of Oil, Gas, and Sand during Cleaning Operations of a Plugged Oil Well

responding slot cut in the collared end, thus enabling the rods when connected to be rotated in either direction without unscrewing.

To secure a maximum of torsional strength with a minimum of weight as well as to furnish means for flushing the well if advisable,

heavy solid drawn tubing is now being used for fishing rods, joints similar to those described above being used.

For positive acting fishing tools the above rods cannot be surpassed, and they constitute part of the customary equipment of modern drilling contractors and large drilling companies. In America, for the more difficult fishing operations, special tools are lowered on a string of casing or drive pipe, but the advantages of rods over this latter practice are obvious.



Roumanian Hollow Fishing Rod.

Russian Solid Fishing Rod.

Fig. 82.—Fishing Rods or Poles.

Heavy solid drawn tubes with long left-handed threads are used for fishing in the Roumanian oil-fields. The resistance of a long thread is sufficient to ensure a grip being taken on lost objects, but the left-hand threads allow the tools to be released without the danger of unscrewing if the tool cannot be moved.

Portable Drills.—The expense of dismantling and re-erecting a derrick and rig at each well site has long been a source of concern amongst operators where wells can be completed in a week or two, and more time is occupied in transportation and re-erection of rig than in the drilling. When drilling occupies one or two years, as in Russia, Galicia, and parts of Roumania, the derrick is converted into a workshop, windows being fitted, heating appliances installed for winter, and everything comfortably arranged.

Much ingenuity has been displayed in the design of portable rigs capable of drilling from 500-2,000 ft. in average ground. In attempts to replace the heavy wooden structures by light iron framing, the part played by flexible material has been well disclosed; nevertheless, exceedingly serviceable drills mounted on wheels have been produced, and they have been extensively used in certain countries where the drilling is simple, little and light casing is required, and the contours of the ground are easy. It is, however, rarely that they will accomplish the claims of manufacturers without serious deterioration, and such should never be attempted in practice. Portable boilers are usually provided separately, on account of the great additional weight of the boiler and the danger attending its proximity to the well.

Two portable drills, the "Star" and "Columbia," have attracted special notice in America, and found extended employment in many of the shallow, easy-drilling territories of that country. The "Star" is exceedingly simple and partakes of modified designs for various sizes. Size 28, catalogued for 3,000 ft., is a representative type. A strong timber framework carrying the engine and gear is mounted on wheels with 8-in. tread. The vertical engine of about 26 H.P. is fitted with a pulley (A) through which power is conveyed to the band wheel (B) by means of a 16-in. belt. Attached to the shaft (C) which carries the band wheel, and at the opposite end, is an overhanging crank (D) to which is connected the pitman or connecting rod (E) for putting into motion the walking beam (F), from the extreme end of which are suspended the rope and drilling tools. The bull wheel or main rope drum (G) is fitted with a spur wheel which engages with a sliding pinion mounted on countershaft (H), to the other end of which is fitted a friction pulley (I) that can be drawn against the periphery of the band wheel.

The sand reel (J), carrying the bailing line, is operated by means of a friction pulley brought into contact with the inner periphery of the band wheel. The calf wheel or casing line drum (K), which should be provided for handling casing, is mounted on the band wheel shaft and is put in and out of gear by a clutch. Spudding gear, by means of which a reciprocating motion is given

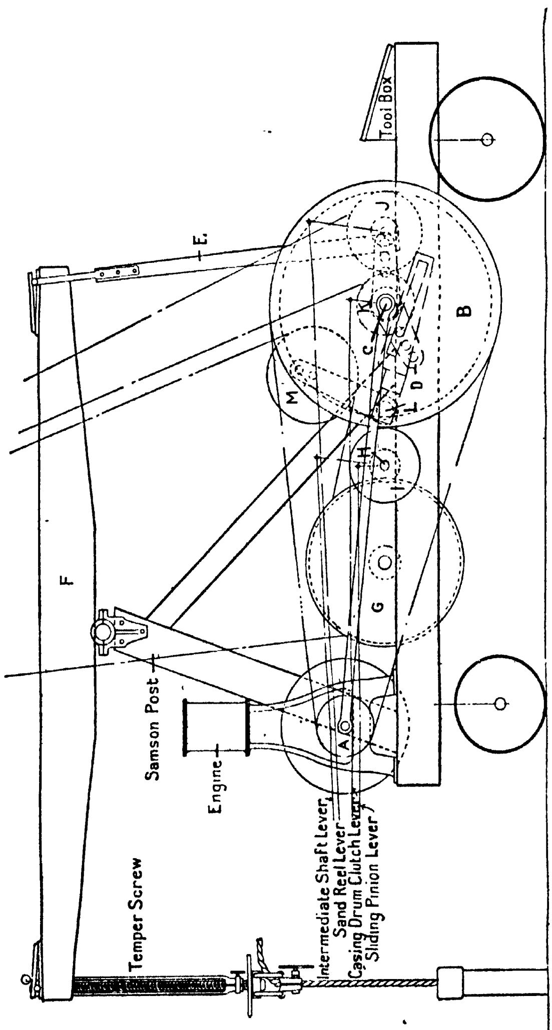


Fig. 83.—"Star" Portable Drill (Diagrammatic Sketch).

The casing drum I is mounted on the engine shaft H, and is operated by clutch gearing. The framework is of timber.

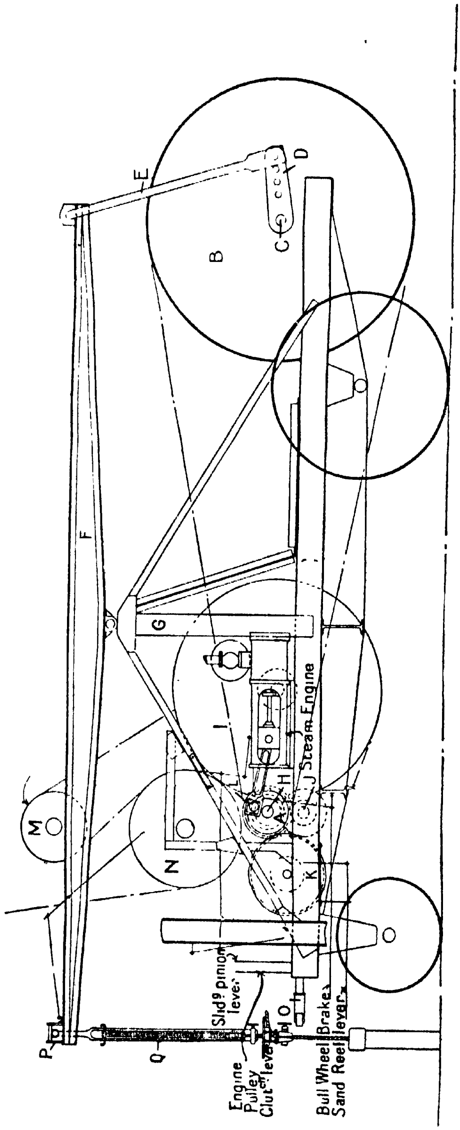


Fig. 84.—"Columbia" Portable Drill Diagrammatic Sketch).

An all steel framework rig that has achieved a reputation.

to the tools when the well is started, and before sufficient depth is drilled to enable the walking beam to be operated, is actuated by the overhanging crank (D). A slotted lever carrying a sliding block into which the crank-pin is fitted, conveys a reciprocating movement to the shaft (L), to one end of which it is connected. Mounted on this shaft is a rocking lever carrying a grooved pulley (M) over which the bull rope from which the drilling tools are suspended is passed on its way from the bull wheel (G) to the top of the derrick or mast.

Movement of the shaft (L) causes alternative tightening and slackening of the rope, thus raising and more rapidly lowering the tools, causing them to penetrate the soil. The monkey or stem for driving drive pipe may be operated in this way.

All the drums are fitted with brakes which are controlled, together with all operating levers at the front of the machine. Where the hole has to be lined with casing it is customary to employ a derrick, but if the quantity is small and no great strains are exerted, a mast may be substituted.

The "Columbia" portable drill differs from the "Star," in that it is constructed wholly of iron and steel. The steam engine of size No. 10, catalogued for 2,000 ft., which is selected as an illustration, is of the horizontal type, about 20 H.P. It is mounted on the steel H-section framework and is fitted with a pulley (A), 14-in. face, from which, by means of a belt drive, power is conveyed to the band wheel (B). The band wheel is mounted inside the frame and is fitted to a shaft (C) with two overhanging cranks (D), which engage with connecting rods (E) to operate the walking beam (F). Unlike the "Star" machine the walking beam is constructed of two parallel built-up steel girders (F) mounted on standards or sampson posts (G) attached one on either side of the framework of the machine.

The main engine shaft (H) carrying the engine pulley (A) runs in bearings on either side of the framework, and is fitted with a sliding pinion with three positions: the first engages the bull wheel (I), the central position is neutral, and the third engages with the back shaft (J). The sand reel (K) is operated by friction from the back shaft (J).

Spudding is effected by conveying the rope from the bull

wheel (I) over a pulley (M) attached to the upper side of the walking beam and thence over a second pulley (N) to the derrick. The oscillating walking beam gives the necessary motion to the tools. As with the "Star" rig, tubes can be driven by this means.

A feature of this rig is the means provided for screwing and unscrewing casing. A rope attached to the casing drum (L) also encircles the tubes two or three times, the free end being held to keep the rope taut. By rotating the drum the tubes are also

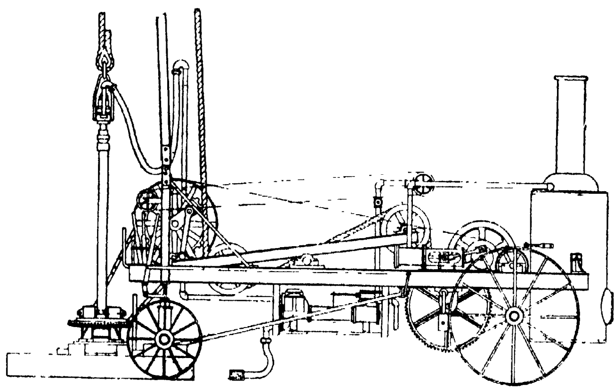


Fig. 85.—Small "Columbia" Portable Drill, with Rotary Attachment.

Designed for the purpose of enabling rapid interchange between the percussion and rotary systems of drilling, thus securing the advantages of both when penetrating alternate thick beds of hard and soft strata.

rotated in either direction depending on the direction of winding round the tubes. A special bracket (O) is fitted to the front of the rig framework against which the tubes are forced by the pull on the rope. This bracket is fitted with rollers to minimise friction. All operating levers are concentrated at the front of the machine and can be manipulated without difficulty by one man. Either a derrick tripod or a mast may be employed with this machine according to the amount of casing to be used in the well.

In order to obviate the necessity of connecting and disconnect-

ing the pitman when the walking beam is not in use, the engine pulley is fitted with a clutch which can be disengaged at will. The headpiece of the walking beam (P) carrying the temper screw (Q) may be displaced at will, thus leaving no obstacle in the way during cleaning, bailing, or casing operations.

Cost of Drilling.—The cost of drilling and lining wells varies greatly in different fields, and is dependent upon a number of factors, of which the following are the chief:—

a. Diameter.
b. Depth.
c. System of drilling.
d. Cost of power.
e. Amount and kind of casing.
f. Labour rates.
g. Presence or absence of water needing exclusion.

The power may vary between extremes of 10 and 75 H.P., the heaviest loads only being sustained for brief periods. It is difficult to indicate the power of engines working under such a fluctuating load as in drilling, but it is possible to calculate backwards from the fuel consumption per day the approximate average power demanded. Cable-drilled wells of moderate depth and diameter take about 7 barrels (say 1 ton) of oil daily; deeper wells use 10 barrels (say 1.5 tons), and circulating or hydraulic flush processes consume as much as 15 barrels (say 2 tons) of oil per diem. With steam there is great waste through condensation, due to periods of intermittent working. Assuming an evaporation of 12 lbs. of water per lb. of oil (a boiler efficiency of about 65 per cent.) and a steam consumption of 50 lbs. per B.H.P. hour, the power would be as under:—

At 7 barrels daily	= 0.3 barrel	= 90 lbs.	per hour	= 21.5 H.P.
At 10 „	= 0.42 „	= 126	„	= 30 H.P.
At 15 „	= 0.63 „	= 189	„	= 45 H.P.

Electrical energy leads to great economy in power consumption as the current can be shut off during periods of stoppages, and no heavy radiation losses continue during periods of low power consumption. Thus in the Baku oil-fields the average power consumed

by using electrical energy is only 8.5 kw. per hour, 11.4 H.P., with maximum requirements of 75 H.P. In Roumania the average cost of electric power for drilling wells is about 20 fr. ($4) a day, representing a charge of about 2.50 fr. (50 cents) per foot in average wells of moderate depth. Some indicator tests of a steam engine drilling in the Coalinga oil-fields of California gave the following results:—[1]

Lifting tools - - -	20 H.P.
Bailing - - - -	10 H.P.
Raising sand pump - -	22 H.P.
Drilling - - - -	10-14 H.P.

The actual cost of power can be calculated from the above figures, as well as the cost per foot of hole. If gas is used, 45,000 cub. ft. may be taken to equal 1 ton of oil, or 6,000 cub. ft. 1 barrel.

Casing requirements in wells differ widely, and are dependent upon the following factors:—

a. Class of casing needed to support walls.
b. Freights and transport from works to sites.
c. Price of metal
d. Number of water sources to be excluded.

In table on p. 592, the proportionate cost of casing may be noted. The average cost of casing used per foot of drilling can be calculated for circumscribed areas, and used as a basis of calculations. Baku wells, 2,000 ft. in depth, with initial diameters of 36-42 in., often necessitate the employment of 300 tons of steel.

Analysis of 133 Coalinga wells showed the cost of casing per foot to average:—[2]

$2.70	in wells to 1,500 ft.,	averaging	1,305 ft.	deep.
$4.00	„ 2,000 „	„	1,844	„
$4.44	„ 3,000 „	„	2,450	„
$4.58	„ above 3,000 ft.	„	3,332	„

Roumanian wells of about 1,500 ft. in depth use casing to the value of about $8 per foot, and in Burma the cost fluctuates around $3 per foot.

[1] [2] "Petroleum Industry of California." *Loc. cit.*

Labour may fluctuate in cost between $5 to $30 (£1 to £6) per diem, and the total cost of wells may be between extremes of $1.50 and $30 (6s. and £6) per foot.

Suppression of Wild Oil and Gas Sources.—There are sometimes reasons for drilling through several oil sources, either to tap a known deep source or to prospect for deeper horizons. Prolific oil or gas sands may be passed by cautiously working with a hole full of water, and avoiding anything that might induce a flow, but at other times the water is expelled and more or less violent eruptions of gas or oil prevent further progress until the gas or oil is sufficiently exhausted to allow casing to be manipulated or drilling continued. In the Mid-Continental oil-fields of America, sands containing gas under pressures of from 300-800 lbs. per square inch have often to be passed to reach the oil sands, and the practice of allowing this gas to escape has led the American Government to undertake investigations with a view to effecting its conservation. The experiments conducted with mud have proved exceedingly successful, and demonstrated that powerful sources may be drowned, extinguished, and passed with little loss of gas and at no great expense.

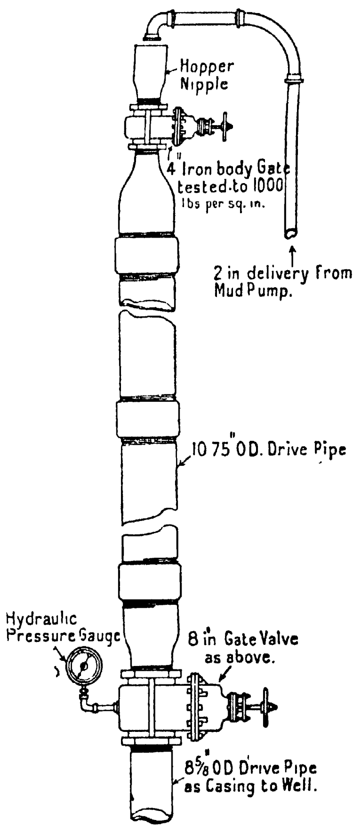


Fig. 86.—Arrangement for Filling with Mud Wells under High Gas Pressure.

When a powerful gas source has been reached, a thick puddle of clay, quite free from sand, is pumped into the well. If the pressure is too high, or the volume of gas too great to allow the

mud fluid to enter the well, a valve is screwed to the casing head, several lengths of 10-in. or 12-in. casing are attached by means of a reducer, and another valve placed either at the top or at a point where a pipe leading from the pump enters the casing. An air valve is required to allow the escape of air and gas from the receiver, and the casing should be securely anchored. The lower valve is closed and mud is pumped into the receiver till full, the air valve being opened to allow the escape of contained air or gas. On closing the upper valve and opening the lower the fluid enters the well by gravity, the lower valve is then closed and the operation repeated till the well is filled. By this means gas sources yielding up to 40,000,000 cub. ft. daily have been rendered inert and passed until the casing has been set securely in suitable material below the gas source. Drilling can then be continued in a dry hole if desired.

Sometimes the above procedure cannot be carried out on account of the high pressure of gas, and the insecurity of the casing already inserted This has been overcome by attaching to the top of the casing a T-piece with the single outlet leading horizontally. On the upper part of the T is fitted a gland and stuffing box, through which 3-in. tubing can be lowered to the bottom of the well. By tightening the gland and slowly restricting the side flow of gas by a valve whilst mud is being pumped into the 3-in. tubing the gas pressure can be ultimately suppressed, and the well left in a state to complete or deepen.

Mud introduced into wells in the manner described is instrumental in excluding water sources by plugging the porous stratum from which the water issued.

Shooting or Torpedoing Wells.—Where petroleum is disseminated amidst hard dolomitic limestones or calcareous sandstones, or where lateral variation of texture in hard rocks leads to the irregular distribution of petroleum throughout a bed, considerable benefits are often derived by blasting the oil-bearing rock with powerful explosives. The effect of explosions on hard rock not only leads to the destructive shattering of a productive bed, thereby enabling freer movements of the oil, but it sets up a subterranean disturbance in the oil and gas enclosed under high pressure in the pores of the rock, which continues for a

time. Wells sunk to oil-bearing horizons in the Appalachian oil-fields of America often exhibit little or no indications of oil until they have been "*shot*," after which they frequently flow freely for a while, and give a handsome production. When the oil-bearing stratum is a hard, compact rock the natural infiltration is slow, and a violent explosion will sufficiently crack the bed for a wide radius around to allow the contained oil and gas to flow through the numerous fissures to the well. Likewise the fissuring of an unproductive portion of the stratum by an explosion will sometimes cause a connection with productive parts of the same bed in the vicinity. The failure of a small shot to induce a flow of oil may be followed by success on the firing of a more powerful shot, and likewise the periodical "*shooting*" of a well often causes the production of a well, which has fallen to a nominal amount only, to rise again to a high figure.

In soft, spongy strata no benefit is derived from torpedoing; indeed, the production of oil may be diminished, as the strata are simply powerfully compressed, and oil inlets may be thereby closed. The following notes, taken from a valuable paper by N. M. Fenneman,[1] will give a clear idea of the usual objects and methods of "shooting" wells in the Boulder oil-field of Colorado, the arguments in which apply equally elsewhere:—

"All the wells pumped up to the close of the year 1902 have been shot. The amount of nitro-glycerine used in these shots has varied from 10-120 quarts. Dynamite charges have been as large as 500 lbs., 70 per cent. nitro-glycerine. The effects of these shots have not been uniformly favourable. The beneficial effects in a few of the best wells have doubtless been responsible for most of the later attempts. It is by no means certain as yet that this practice will be universal in this field. At least one well has recently begun pumping without being shot, and the owners have no immediate intention of shooting. The fact that the flow of some wells has decreased since the shooting will lead to greater caution, and it is to be hoped that it will lead to a more careful study of the conditions present in each well.

[1] "Contributions to Economic Geology, 1902," United States Geological Survey.

"The beneficial or harmful effects of a shot must depend largely upon the texture of the stratum yielding the oil, for it seems to be true that some shales are compacted rather than shattered by the explosion. For this reason, shooting is not practised in the Florence field, which, of all the older oil districts, the Boulder field most resembles. Owing to the difference in texture of the various beds yielding oil in the Boulder field, it is but reasonable to expect that the same shot which would prove beneficial to one well would be ruinous to another. On this account, if on no other, the texture and composition of the oil strata should be carefully studied by methods far more discriminating than the superficial ones now used.

"A second reason for injurious effects from shooting lies in uncertainty about the exact depth of the sand which it is intended to shatter. Measurements of depths by steel tape are indeed becoming more common, but in a considerable number of wells the depths of all formations are known only by cable measurement. Even in wells but recently sunk it is not uncommon that the stated depths of important sands are thus liable to errors of 25-50 ft.

"The possible injuries from a shot at the wrong place may be readily seen from the following considerations: Given a porous rock saturated with oil which is under a certain pressure. This rock is now, for the sole reason that it has no outlet in any other direction, being surrounded (as in this field) by impervious rocks. This well is now shot in such a way as to rupture the impervious rocks which have surrounded the oil sand. The oil may now leave the sand by other openings besides the well, and may thus be dissipated in other porous beds and the well may be ruined. Such an effect may be produced even by shooting at the proper depth if the charge employed be too heavy. In one instance a well was shot at 740 ft. with 500 lbs. of dynamite, 60 per cent. nitro-glycerine. The formation above the sand was a uniform dense shale. A good quality of sandstone was blown from the hole in chunks reaching a maximum of 14 lbs. The shale was ruptured to the surface. Open cracks of an inch or more extended for some rods from the well. Presumably, also, cracks reached a considerable depth below the sand which was to be shattered.

"It cannot be too carefully borne in mind that the one object in shooting is to shatter the rock which carries the oil, and that only. With this object in view, it is plain that intelligent and discriminating shooting must depend upon information which the following questions may suggest: Is the texture of the oil stratum such as to give promise that it will be shattered rather than compacted? What is the exact depth of its top (and bottom if drilled through)? How much of a shot will the overlying rocks bear without giving other outlets to the oil? This last question is one of great importance in this field. It is needless to say that such questions can be answered only by a carefully kept log and close study of samples, not only of oil sands, but of all strata, in order to properly forecast their behaviour under the influence of a shot."

The following description of the procedure now adopted on the Kansas-Oklahoma oil-field was contributed by A. A. Ashworth, M.A., A.M.Inst.C.E.:—

"Oil wells in Oklahoma and Kansas are nearly always 'shot' soon after they are drilled in. The shooting of a well consists in exploding a large charge of explosive placed in the bore at the level of the oil sand. In this district a well is hardly considered as completed until it has been shot, and the shooting is only omitted when it is considered that the shot may have a bad effect in causing the well to be flooded out with salt water where the oil sand is small in thickness and immediately overlies a brine sand, or when a string of casing which cannot be pulled out without risk is seated too close to the top of the oil sand and would be liable to damage from the shot.

"The explosive used is almost universally nitro-glycerine. Dynamite has been tried, but has proved unsatisfactory, as with the use of this it has been found difficult to ensure the whole of the charge being fired. If a portion of the charge remains unexploded, it will almost certainly be fired when the tools are being run subsequently in clearing out the well, and in that case the well would probably be irretrievably spoiled.

"The nitro-glycerine is manufactured at the magazine belonging to the nitro-glycerine company in the district in which it is to be used. There are several of these nitro-glycerine companies, and

each company has its magazine in every main district of the field. The explosive is taken from the magazine to the well in carts or automobiles specially arranged for the purpose. When a well is to be shot, the shooter, employed by the nitro-glycerine company, is instructed beforehand of the approximate quantity of explosive required, and this quantity is taken by him from the magazine to the well in rectangular tins each containing ten quarts. Each of these tins is placed in a separate felt-lined compartment of the shooter's wagon or automobile. In passing from the magazine to the well the conveyance is not allowed to pass through towns.

"The amount of explosive used is fixed by the owner of the well or his agent. It will depend mainly on the diameter of the hole and the thickness of the oil stratum, and, in general, the largest amount of explosive that can be placed in the space determined by these considerations is used. Thus, supposing the diameter of the bore were $6\frac{1}{4}$ in., and the thickness of the sand 40 ft., the amount of the charge would probably be 160 quarts contained in eight shells, $5\frac{1}{2}$ in. diameter, of 20 quarts each, each shell occupying a depth of 4 ft. 6 in. This charge would thus occupy 36 ft. of the 40 ft. thickness of oil sand, and the charge would be placed so as to leave the top 4 ft. of the sand above the top shell.

"This top 4 ft. of the sand would probably be sufficiently shattered by the shot to enable it to give its full production, and in any case the cavity formed below would permit all the oil in this 4 ft. to drain downwards without hindrance.

"When the shooter arrives at the well, he takes full responsibility, and in the case of any accident damaging the well, his company is responsible to the owners. As a rule, the shooter asks for the assistance of one of the drilling contractor's men to aid him in putting in the shot, but this does not relieve him of any of the responsibility.

"After his arrival at the well, the first operation is to run the steel measuring line to show that the well is at its full depth, and that the bore is not partially filled by cavings. The owner, or his agent, then instructs the shooter as to the exact points between which he wishes the shot to be placed. In many cases it is not desirable to place the shot at the very bottom of the hole. In these cases the shells are supported at the required distance above

the bottom by attaching to the lower end of the first shell the required length of 'anchor,' which consists of a length, or several connected lengths, of tubing made of tinned sheet iron.

"The shells are lowered by means of a manilla line about $\frac{3}{8}$ in. diameter to the bottom end of which a hook is fastened, which automatically detaches itself from the bale of the shell when this comes to rest. The empty shell is supported in the top of the hole, while the explosive is poured in from the tins in which it is transported to the well. Each shell takes two tins of explosive to fill it. Any drops of nitro-glycerine which may run down the outside of the shell are carefully wiped off to prevent premature firing of the shell due to friction against the casing. The tins, when emptied, are replaced in the wagon.

"The line is paid out by hand, the shooter keeping a careful watch to ensure the shell from sticking in the bore before it reaches the bottom of the hole. When the first shell with the anchor reaches the bottom of the hole, the line is marked as a guide to make certain the remaining shells are lowered to the right position. The line is then withdrawn, and the steel measuring line again run to make certain of the correct position of the first shell. This being ascertained the other shells are lowered, the mark previously placed on the manilla line being sufficient guide to ascertain the correctness of their position.

"When all the shells are placed in position, it may be necessary to pull the inner string of casing should the lower end of this be seated too near the shot. Every shot to be fully effective should have as tamping a head of fluid (water or oil) of from 100 ft. to 400 or 500 ft. in depth. It is important that this fluid tamping should not stand up into the inner string of casing. The result of firing a shot with the fluid standing up into the casing would be the splitting of the casing. Hence this is always removed first, unless there is sufficient room between the top of the shot and the bottom of the casing for an ample head of fluid. In that case, before shooting, the excess fluid is swabbed out until it is certain the level is below the bottom of the casing.

"If there is any danger of caving taking place on the removal of this casing, an electric detonator is lowered with the last shell and the casing is pulled over the insulated cable from the detonator

to the surface. Otherwise the shot is generally fired by means of a squib, which is a tin tube containing a small stick of dynamite, in which is buried a detonating cap connected to a length of fuse which is lighted before the squib is dropped into the well. Where this fails to explode the shot a small tin tube containing a charge of glycerine and a firing head is lowered into the well on a copper wire, and when it is in position the firing head is struck by means of a short length of 1 in. diameter pipe threaded on to the wire and dropped into the well.

"The firing of the shot is generally followed by the ejection of the fluid contents of the bore hole, unless the hole is a deep one and the fluid head large compared to the size of the charge, in which case the shot does not always 'come out.'

"A good well will generally make several strong flows after shooting. After this first flush production has ceased, the well will require a good cleaning out, as for some time the disrupted sand continues to fill up the bottom of the hole, and until this sand ceases to come in cleaning out must be continued, otherwise it would be impossible to pump the well continuously. This cleaning out may take from one or two days to as long as three weeks before the loose sand is got rid of.

"The effect of the shot is to increase the production of the well to a considerable extent. Hard, compact sands are in general most benefited by shooting, but it is impossible to gauge the benefit beforehand. Certain sands give very little 'natural' production, *i.e.*, production without the aid of a shot. A notable sand in this respect is the 'Booch' sand found in the neighbourhood of Morris in the county of Okmulgee. This sand is found at a depth of 1,000-1,200 ft., and was entirely neglected until the effect of a shot was tried on it. Many Booch-sand wells on being drilled in will only produce about half a barrel or so of oil per day, but on being shot will start off at a daily production of one or two hundred barrels or even more. The remarkable effect of a shot in the Booch sand has not been satisfactorily explained.

"The work of shooting wells is naturally very dangerous, and every year a number of shooters lose their lives from accidents. Shooters receive a salary of about $150 per month which cannot be considered high considering the responsible and hazardous nature

of their occupation. It is generally considered that a shooter's final illness will not incur either a doctor's bill or funeral expenses.

"The cost of shooting is estimated per quart of explosive. For a shot of one hundred quarts or over it is $1.15 per quart, smaller charges being at a higher rate."

Contract Drilling.—Wherever reputable contractors can be engaged or qualified drillers can be induced to accept contract work the policy of drilling by contract should be adopted. So much depends upon the actual operator, over whom little direct supervision is possible, that it is advisable to directly interest contractors in the work. There are objections to the pursuance of such a course, for there may be a disposition on the part of contractors to disregard the aims of the proprietor to find oil and confine their energies solely to the drilling of a maximum footage within a minimum period. Oil sources may thus be passed through without being reported unless a close watch is kept. Contractors also do not favour the temporary suspension of drilling to undertake water exclusion measures, during which period they only receive, as a rule, a nominal daily sum to little more than cover expenses; consequently, there is an inclination to conceal the existence of water sources which, if they do not hide the presence of oil, may subsequently cause permanent injury to a producing well. A conscientious boring contractor with his employer's interests at heart will not only faithfully carry out his contract, but advise generally on the course to pursue at each juncture; but it is more satisfactory for both parties if the producer appoints independent inspectors to overlook the drilling.

The form of contract varies in different oil-fields. Sometimes the contractor has to find everything, whilst at other times he is given his power, fuel, and water, or even all the necessary drilling machinery as well. The following is a translation of the usual form of contract for drilling the wells in the Baku oil-fields, which is as full as any contract made anywhere, and foresees almost every contingency connected with drilling oil wells:—

1. The Firm has given over to the Boring Contractor, and the latter has taken over for boring, well No.   on Plot No.   . Not later than   the Firm must give Contractor a correctly built and fully equipped derrick, as detailed in Clause 2 of this Agreement, and the Contractor

must, within thirty days of taking over the boring, commence work and continue it night and day with his foreman, workmen, and instruments, and with his own boring rig, until reaching an oil source which shall be considered by the Firm sufficient for exploitation, but not necessarily deeper than 250 sagens (1,750 ft.).

2. The Firm supplies a derrick covered with some fireproof substance with all appliances, a completed shaft with guide and floor, a completed foundation for boring rig made according to Contractor's instructions, a bailing pulley, a steam engine or electric motor of not less than 60 horse power, with sufficient energy necessary to run the same, four electric lamps—one being portable, convenient roadway to the derrick, a bridge at the side door of the derrick, and also deliver to the well good quality iron casing of not less than ¼ in. thickness riveted in columns of two, three, or four tubes, according to the desire of the Contractor, a double template for testing the tubes, rivets, clay, cement, and hard stone for stamping down shaft and well, also water, which must be delivered in requisite quantity by means of the property pumps to the mouth of the well. For trial bailing the Firm supplies rope, belt, and bailer, and for cementing all necessary materials and appliances. The Contractor has use of all the above, and is supplied with them whenever required, and for all the time work is carried on in the well.

Note.—Care of the engine, oiling and repairs of same, also keeping in repair derrick, electric light, and also fire-extinguishing apparatus, must be performed by the Firm.

3. Boring must be commenced with shaft tubes of 32 in. diameter, and continued with tubes of 30, 28, 26, 24, 22, 20, 18, 16 in. diameter in such a manner that the mean depth of each column passing into the ground shall not be less than 30 sagens (210 ft.), excluding from the total depth the depth of the shaft column, safety column, and those columns stopped on account of the non-fulfilment on the part of the Firm of the conditions set out in Clause 2 of this Agreement, and those columns stopped on account of fire, on account of the sudden disappearance of liquid in the well, or on account of the entry of cement into the well. Columns of casing stopped for the above reasons are not taken into account when making up the mean depth bored, if, in such cases, the column has passed down less than 30 sagens. If, on delivery of the well, it should appear that the Contractor has not carried out this obligation, and has lowered more tubes than necessary in order to drill 30 sagens with each column, then the extra number of columns of tubes will be for account of the Contractor at cost price. The Contractor is freed from above obligation if columns of tubes are stopped or pressed into clay at the request of the Firm, or become stopped on account of trial bailing or fountains.

4. If in the course of boring, owing to the fault of the Contractor, the well should become so damaged that further boring is impossible, and the Contractor finds it impossible to repair same, then the Contractor must transfer the derrick to another place on the same property, and without charge bore there another well with his own casings of the same diameters to the depth of the spoilt well. At the same time the Contractor has the right at his own cost to withdraw casings from the damaged well, and use them as he may see fit. If, however, the well has become damaged on account of trial bailing, a fountain, fire, appearance of gas, sudden disappearance of liquid, cementation or pressing column down at request of the Firm, and similar reasons, then for the results of

such the Contractor does not answer, and the repair of the well will take place for account of the Firm, and by special agreement on both sides.

5. On demand by the Firm, the Contractor must carry out the following :—

(*a*) By means of a centring apparatus to test the well for verticality up to a depth of 140 ft., and the well is considered vertical if the displacement of the column to one side at 140 ft. does not exceed 1 in.

(*b*) Before proceeding to trial bail after cementing, and also before pressing down a column, to lower a column of four tubes 2 in. less in diameter than the last casing, and the well to be considered in order if this column passes to the shoe.

(*c*) To cut out columns at depths determined by the Firm, not, however, at a lower depth than 35 ft. above the depth of the previous shoe.

(*d*) To stop or press down a column of tubes at any depth, to carry out cementation, trial bailing, cleaning plug, and other work, as may be determined by the Firm, and at their responsibility.

(*e*) To measure the length of the column with shoe fork.

6. For every sagen drilled up to 100 sagens boring is carried out at the basis price of 100 roubles, thereupon for every additional 10 sagens above 100 sagens bored to the basis price is added 10 roubles per sagen, *i.e.*, the cost per sagen for boring from 100 to 110 sagens is 110 roubles, for boring from 110 to 120 sagens is 120 roubles, and so on. Measurement of depth takes place from the floor of the derrick to the bottom of the well. (A sagen is 7 ft. ; a rouble 2 shillings or 48 cents.)

7. For all work not connected with actual drilling of the well, such as ramming down and strengthening the shaft, making and cleaning artificial plug, cementing, trial bailing, cleaning plug, and moving columns after trial bailing, fishing for and taking out instruments lost while carrying out any of this special work, also taking out instruments seized by cement, and other such work with the exception of cutting up casing, the Firm pays the Contractor 40 roubles (£4. 5s. or $20.4) per day.

8. If any column of tubes stops on account of trial bailing, fountain, fire, entry of cement into the well, or on account of non-fulfilment by the Firm of Clause 2 of this Agreement, or if any column of tubes has been stopped at the request of the Firm, and if the columns stopped for any of the above reasons have been drilled into the ground less than 280 ft., then the lowering of the next column of tubes to the shoe of the previous column shall be for account of the Firm at 4 roubles per sagen of tubes lowered, such charge being also made for lowering safety column of tubes. In all other cases the Contractor lowers columns of tubes at his own expense.

9. Cutting and taking out columns of tubes is carried out at the price of 4 roubles per sagen of tubes withdrawn, such tubes being unriveted in columns of four tubes each. If after several attempts at cutting, the column comes away at the top cut, the remaining pieces of cut column have to be raised by means of tube catcher and fishing rods, then this work will be carried out by special agreement on both sides.

10. For all stoppages of work the offending party shall pay the other party 40 roubles ($20) per day. The Contractor shall receive this 40 roubles per day also if the stoppage has occurred on account of a fountain in the neighbourhood. For stoppages and results of such stoppages caused by act of God, strikes of workmen, national disturbances, boiler explosions, fire, etc., both sides are freed

from any responsibility, but in case of fire the Contractor has the right to remove his property from the derrick until it shall have become possible to resume the interrupted work.

11. Settlement of accounts between both parties shall take place in cash once a month, not later than the 15th day of the month, for work carried out by the Contractor during the previous month.

12. The Contractor has the right to stop work and remove his property from the well without incurring any responsibility for such stoppage and the consequences thereof, in the following cases -

(*a*) On reaching the limit depth of 250 sagens, should no additional agreement have been arrived at by the parties for the continuation of the work.

(*b*) On final stoppage of 8-in. column of tubes.

(*c*) On stoppage of work through the fault of the Firm for thirty days consecutively.

(*d*) After two months' trial bailing and cleaning plug, should no further deepening of the well take place after this period.

(*e*) On non-payment at the time mentioned in Clause 11 of sums due to the Contractor.

13. The Contractor takes full responsibility (criminal and civil) for all accidents occurring to his workmen in the course of carrying out the work, as laid down in this Agreement, and must fulfil all legal demands of the Authorities having connection generally with such work, for which he must prepare a special signed document embodying the above in legal form for handing in to the Second Caucasian District Mining Department

14. The Contractor must keep daily records of boring work, and hand same in the form of daily boring reports to the Firm's property office, and must allow the Firm's representative into the derrick at any time to supervise and check the work. A boring report to which no objection has been received within three days shall be considered accepted, and cannot be disputed after the lapse of the above-mentioned three days. All orders, declarations, and objections of the Firm to the Contractor must be in writing.

15. In case a stoppage of work for a period of thirty days consecutively has taken place through the fault of the Contractor, then the Firm, having first completed payment for work performed, may refuse further work to the Contractor, and may consider the Agreement cancelled without further consequences for either side.

16. All disputes and misunderstandings of a technical nature arising out of this Agreement shall be settled (within one month from date of declaration by one of the parties giving notice of his desire to that effect) by three experts in Baku, each party electing one expert, and these two experts electing a third.

17. On account of the indeterminate nature of the sums to be paid under this Agreement, the latter is stamped with a bill stamp value 1.25 roubles on condition that, the regular payments being made each month, both parties will pay the bill tax equally.

In the American oil-fields the contractor is sometimes furnished with a drilling rig, casing, and power, but must himself find the tools and be responsible for fuel, water, drilling cables, sand lines,

and small accessories. The following agreement is a typical form used by one of the largest oil-producing companies in the eastern oil-fields of the United States:—

THIS AGREEMENT, made this day of A.D. 18 , between of parties of the first part, and the OIL COMPANY, party of the second part.

WITNESSETH, That the said parties of the first part have covenanted and agreed with the said party of the second part, its successors and assigns, that said parties of the first part will drill for said party of the second part a certain well for the purpose of obtaining petroleum oil or natural gas, to be known as WELL NO. on the farm of township county .

The material, machinery, and appliances necessary for drilling and completing said well shall be furnished, and the work of drilling the same shall be done in the manner hereinafter specified, viz.:

A complete carpenter's rig of good quality (including wooden conductor) to be furnished by the party of the second part, and all repairs on same while the well is being drilled shall be made by and at the expense of said parties of the first part.

All casing to be furnished by party of the second part.

Boiler, engine, belt, bull rope, steam and water pipe, and connections to be furnished at the well by party of the second part.

The expense of fitting up and connecting same to be borne by parties of the first part.

Fuel to be furnished at expense of the parties of the first part.

Water to be furnished at the expense of the parties of the first part.

Oil saver and steel measuring line at expense of the parties of the first part.

All machinery, material, and appliances furnished by said party of the second part shall, at the completion or abandonment of said well, be returned to said party of the second part in as good condition as when received by said parties of the first part, ordinary wear and the action of the elements alone excepted.

The said parties of the first part further agree to pay all expenses and furnish everything necessary to drill and complete said well, except the articles and appliances herein specifically mentioned to be furnished by the party of the second part.

The said well, unless sooner abandoned by direction of the party of the second part, is to be drilled to 2,000 ft., the consideration for which shall be two dollars per foot.

All fresh water shall be cased off with a casing of a diameter of not less than in., and all salt water cased off with casing of a diameter of not less than in.

The diameter of the well when completed shall not be less than in.

The outside strings of casing, viz., the in. and in., shall be pulled at the expense of the party of the second part.

When the said well reaches the oil or gas-bearing sand, the method of drilling through the same shall be under the direction of said party of the second part, or its agent in charge of the farm or lease, and if oil or gas is found in sufficient quantities to endanger the rig and material by fire from

the boiler, then said parties of the first part shall, without delay, and at second party's own expense, move the boiler to a safe distance from the well. All pipe fittings made necessary by such removal to be furnished by the said party of the second part.

When completed, unless prevented by too great a volume of gas or oil, the well shall be thoroughly "bailed" and "sand pumped" by the said parties of the first part, until all drillings and sediment are removed therefrom and the well thoroughly cleaned.

The parties of the first part shall carefully examine all machinery, casing, and other appliances to be furnished for said well by the party of the second part, and if any defect be found therein sufficient to make the use of such machinery, casing, or other appliance unsafe, shall immediately notify the party of the second part of such defect or defects, and the party of the second part shall at once replace the articles so found defective with a good and safe one; but if the parties of the first part shall not make such examination, or shall not report any defects in said machinery, casing, or other appliance, they shall be deemed to have assumed all risks and all responsibility for any mishap which may occur in the drilling of said well by reason of a failure in such machinery, casing, or other appliance.

No part of the contract price above mentioned shall in any event be paid until said well shall be completed to the depth above required, and delivered to the party of the second part in thorough good order, free and clear of all obstructions.

The parties of the first part agree to begin the drilling of said well within thirty days from and prosecute the work actively and continuously (Sundays excepted) to completion.

IT IS FURTHER AGREED, That time shall be of the essence of this contract, and that in case the parties of the first part shall neglect or discontinue the work of drilling said well for the space of ten days, such neglect or discontinuance shall of itself be a forfeiture of all rights and claims of the parties of the first part under this agreement without any notice or demand by the party of the second part. The party of the second part shall have the right at any time after such forfeiture to take possession of said well, discontinue the drilling thereof, and at its pleasure dismantle or abandon the same without liability to the parties of the first part for any portion of the contract price above-mentioned. The party of the second part shall also have the right at any time after such forfeiture as above-mentioned, if it so elects, to take possession of said well and all the ropes, tools, and appliances thereat of the parties of the first part, and drill said well to completion. In case it shall succeed in completing said well, the cost of such completion without any allowance to said parties of the first part for the use of the said ropes, tools, and appliances, shall be deducted from the contract price above-mentioned, and the balance, if any, paid to the parties of the first part; but if said party of the second part should not succeed in completing said well, it shall not be liable to the parties of the first part in any sum whatever, and shall return said tools, ropes, and appliances to the parties of the first part in as good order as when received, natural wear and tear and accidental loss or breakage excepted.

IN WITNESS WHEREOF, the parties of the first part have hereunto set their hands and seals, and the party of the second part has caused these presents to be signed by its representative, the date first above written.

Below is the draft of a somewhat comprehensive agreement adapted to circumstances where the contractor is furnished with rig, boiler, fuel, tools, casing and sundry fittings, and is applicable to fields far removed from supply centres, where contractors would be quite unable to provide themselves with requirements. The agreement has proved quite satisfactory in practice.

THE CONTRACTOR AGREES:—

Drilling.—1. To drill wells at such spots as shall be indicated by the Company's representative, each well to be drilled to a maximum depth of ft., unless oil be found in sufficient quantities at a less depth. The Company's representative shall be the sole judge of what are sufficient quantities, and the Company reserves the right to suspend operations and/or take over any well or wells at any depth and at any time that in the opinion of the Company's representative it shall be deemed advisable, upon giving notice in writing to the Contractor of its intention to suspend such operations or to take over any such well or wells.

2. To line the wells in accordance with the prescribed practice and/or the reasonable requirements of the Company's representative, carrying each column of casing as far as possible except when used for water exclusion; and to adopt suitable measures for the total exclusion of water if met with, carrying out special measures if ordinary measures fail.

3. To consult with the Company's representative regarding the size and nature of casing to be inserted, but to use every endeavour to penetrate the oil-bearing sands with as large a diameter as possible, commencing with diameter casing, as it may be mutually agreed, but in no case is the final column to be less than casing, except upon agreement with the Company's representative.

4. To extract as far as possible all casing which may be required by the Company's representative on the completion of a well, or to cut or perforate casing, or insert liners in lieu of casing removed, or other such work preparatory to the completion of a well and which may be required by such representative.

5. In the event of his failing to reach either the requisite depth of ft. or oil in paying quantities before that depth by reason of the small diameters of the hole, damage, accidents, or other causes connected with the execution of his work and for which he may properly be held responsible, the Contractor shall as far as possible extract all casing at his own expense, and pay to the Company the value of all tools lost in the well, and in such case the Contractor shall be paid for the footage drilled at half the scheduled rate mentioned in Clause 32 hereof, provided that such remuneration shall be only payable to the Contractor if the well is at least ft. deep.

6. In case he fails to shut off water so that the well has to be abandoned, to extract as much casing as is possible and fill up the hole at his own expense, payment being made in such case at half the scheduled footage rate mentioned in Clause 32 hereof.

7. To furnish the Company's representative with complete reports every twenty-four hours in such form as may be prescribed by the Company, as well as with samples of the strata that may be encountered, and to immediately

report to such representative the presence of any water, oil, or gas met with during the progress of drilling.

8. In cases where oil is struck in any well in quantity sufficient to justify its acceptance by the Company to hand over such well to the Company on completion thereof, ready for pumping, with all pipes, rods, etc., in position to the surface of such well if so desired by the Company.

Plant and Material.—9. To keep all machinery and plant in good working order, and to immediately report any damage necessitating workshop repairs.

10. To return to the Company on the expiration of the contract, and in good condition, all plant loaned by the Company, due allowance being made for reasonable wear and tear.

11. To carry out at his own expense all small repairs, such as sharpening bits and drills, renewing packing in leaking joints, packing glands, etc.

12. To collect all small tools and account for all plant loaned by the Company at stated periods, to be decided upon by the Company's representative, for the purpose of inventory and inspection.

13. To pay to the Company the value of any small tool which he may be unable to produce for inspection when so required to do by the Company; receipts being exchanged between the parties hereto for any such material issued or returned.

Erection of Plant.—14. To erect his own rigs and machinery and to make his own steam, water and oil connections, the materials for such purposes being delivered by the Company to the Contractor on the site of drilling and the various steam, water and oil lines being laid by the Company up to the well site.

Trial Pumping and Bailing.—15. To conduct trial pumpings or bailings whenever called upon by the Company's representative to do so, provided that in the event of such trials exceeding a total period of three days in any one well, the Contractor shall receive remuneration at the rate mentioned in Clause 33 hereof for any period exceeding such three days. Should the result of such test pumping or bailings prevent the Contractor from reaching the maximum depth of ft. through delays, caving or other causes, the Contractor shall be relieved of any responsibility for not reaching such depth.

Labour.—16. To provide at his expense all labour requisite for the work hereby undertaken by him at a rate of wage not exceeding the current rate of wage paid by the Company to its employees, provided that the Contractor shall at the same time retain the right to make extra payments to his employees at his own expense in the form of a bonus, but not otherwise.

17. Not to employ without the consent in writing of the Company's representative first obtained, any person or persons who may be in the employment of the Company, or who shall have been on the Company's pay roll within three months previous to such person's or persons' proposed employment by the Contractor, or who may have been discharged by the Company for misconduct.

Quarters.—18. To maintain in a clean and sanitary state all buildings and quarters provided by the Company for the Contractor and his employees under Clause 29, and to repay to the Company the cost of repairing any wilful damage done thereto either by the Contractor or by any of his employees.

19. To continue operations without interruptions unless for causes beyond his control, and to fulfil all Government or other regulations which may be imposed by the authorities.

20. To allow to the Company's representative free access to the wells at

any time for the purpose of measurement thereof or for any other purpose whatever.

21. To exercise strict economy in the consumption of fuel, water, and materials supplied by the Company, and to use whenever possible natural gas in lieu of other fuels.

22. Not to divulge either during the continuance of this Agreement or at any time after the determination thereof to any person or persons, firm, company, or syndicate, without the consent of the Company in writing, any information concerning the Company's undertakings or any information which may come to his knowledge during the performance of his duties.

THE COMPANY FOR ITS PART AGREES :—

Engagement.—23. To engage the said Contractor to drill upon its properties an aggregate footage of ft.

Plant and Material.—24. To provide the Contractor free of charge with drilling rigs, machinery and customary sets of tools and appliances sufficient for drilling at least wells simultaneously.

25. To provide the Contractor with casing, piping, fittings, and such materials as may be needful for the execution of the work hereby undertaken by the Contractor, such materials to be delivered by the Company in good order when and as required at the site of the well (provided reasonable notice be given by such Contractor of his requirements) and to renew the same from time to time provided the wear and tear thereof has been reasonable.

26. To provide a stock of usual small stores, fittings and also spare parts for machinery and plant on the site of any well when required, provided reasonable notice of his requirements be given by the Contractor.

27. To furnish water, fuel, and light, due regard being paid by the Contractor to Clause 21 hereof.

28. To execute all workshop repairs with as little delay as possible ; small repairs as specified in Clause 11 hereof being carried out at the Contractor's expense.

Quarters.—29 To provide suitable furnished quarters for the Contractor and his drillers, and to arrange for a supply of drinking water.

Medical Attention.—30. To permit their Medical Officer to professionally attend the Contractor and the Contractor's employees free of charge. Provided that neither the Contractor nor his employees shall be entitled to such professional attendance free of charge in case of illness caused by the excessive use of intoxicants or by any dissipation contrary to a reasonably regular life.

Remuneration.—31. On the completion of a well to send a representative to decide by special measurement or other means to the satisfaction of the Company the depth for which payment is to be made.

32. To pay to the Contractor per foot drilled by him, provided that in the event of oil being found in sufficient quantities (of which the Company's representative shall be the sole judge) at a less depth than ft., or in the event of the Company taking over any well at such less depth, the Contractor shall be paid for a minimum of ft. in respect of each hole drilled by him.

33. To pay to the Contractor per diem during such time as he shall be engaged in extracting casing from wells or when executing at the request of the Company any special work such as excluding water by cementing or packer or perforating casing. Also to compensate the Con-

tractor for any delays for which the Company can be properly held responsible under the terms of this Agreement, provided always that such delays be not due to the Contractor's default in giving reasonable notice to the Company of his requirements and provided also that such delays be not due to circumstances over which the Company has no control. In the event of the Company compensating the Contractor for any delays as aforesaid the Company shall be entitled, upon its making application for such purpose to the Contractor, to utilise temporarily the services of the Contractor's employees, for which services the Company may have paid compensation to the Contractor.

34. To pay to the Contractor   daily for any period exceeding five days occupied by the Company in transferring the plant (after the same shall have been dismantled by the Contractor, and prepared by him for removal) from a finished well to a new site. The Contractor giving every assistance in the removal when so compensated.

Settlement of Accounts.—35. To adjust and pay all accounts between itself and the Contractor monthly, but it is mutually agreed that the Contractor shall not receive a larger sum than 75 per cent. of the amount due to him on account of uncompleted wells, the balance of 25 per cent. being retained by the Company as a guarantee of the completion of this contract by the Contractor. Should the Contractor become liable or indebted to the Company in any sum or sums of money under the terms of this contract, the Contractor shall pay to the Company or satisfy the amount of his liability of indebtedness before he shall be entitled to draw or receive any further moneys from the Company.

36. Each well shall be considered a separate account for the purposes of payment.

CHAPTER VIII.

CASING OR LINING TUBES FOR WELLS AND APPLIANCES EMPLOYED IN ITS INSERTION, MANIPULATION, EXTRACTION, AND REPAIRS.

Objects of Casing—Types of Casing—Casing Shoes—Methods of Ensuring Freedom of Casing—Casing Clamps and Elevators—Cutting and Removing Casing—Recovering Lost Casing—Perforating, Punching, and Slitting Casing—Repairing Damaged Casing—Testing Verticality.

Objects of Casing.—An essential feature of well boring is the lining of wells. Except where hard compact strata are known to extend to the aspired-to depths, provision must be made for supporting the walls when passing friable strata which would spontaneously run or crumble and fall in the hole if left unsupported or become loosened by the vibration of the drill rods or cable. Long distances of inclined caving ground or periodical seams of friable or uncompacted material hinder, and eventually check the movement of a column of tubes by lateral pressure, after which a smaller size of casing has to be inserted, and drilling continued with smaller tools. The possible contingency of having to periodically exclude water sources must not be overlooked in fixing the initial diameter of a well, as in some oil-fields several water-bearing beds may have to be separately attended to. This reduction in the size of casing may have to be repeated a number of times dependent upon the nature of the strata, so that the well ultimately takes a telescopic form. Judgment is therefore needed in deciding the initial diameter of wells to reach an estimated depth with a desired diameter, otherwise an unserviceable size is reached before the required depth is attained, and the whole work may prove worthless. Customary means of economising casing and diminishing the effect of lateral pressure will be described in succeeding paragraphs.

The importance of such economies will be better appreciated by calculations which will show that the cost of purchasing, transporting, and handling a single column of tubes for a deep well may represent an addition of several hundred pounds sterling, even allowing for a high valuation of part of the column eventually recovered.

Types of Casing.—Bore holes up to 14 and even 18 in. are now usually lined with screwed casing, which has become more or less standardised in the United States. The main features distinguishing well casing from ordinary tubing are the following:—

(*a*) Screwing must be clean and absolutely true, so that tubes are in perfect alignment when coupled. The first few threads of casing are flat to allow the screwing to start easily without damaging the thread. The collars are recessed about ¼ in. to protect the threads and simplify screwing up.

(*b*) Tubes must be quite circular to allow tools to pass freely and to ensure equal thickness at threads, as the whole weight of a column of several thousand feet may be suspended from a single socket.

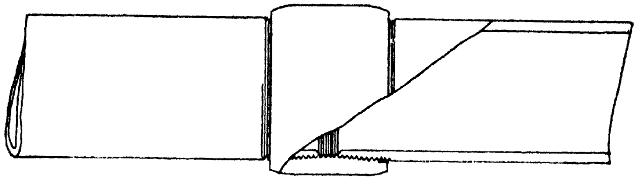
(*c*) The threading, whilst ensuring a water-tight joint, should be sufficiently coarse to enable tubes to be easily and quickly connected at the well.

(*d*) The ends of tubes must be slightly chamfered internally to remove all burrs which would cause undue wear of cables.

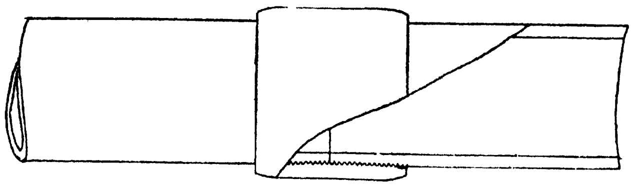
(*e*) Whatever the thickness of casing, the external diameter should not be varied, so that two weights of casing can be coupled, and all the expensive appliances for handling or manipulating casing can be used for one nominal diameter.

(*f*) Material should be a mild steel of about 25 tons tensile strength per square inch, and elongation of 20 per cent. in 8 in. Too soft a metal leads to damage and to bulges when screwing up, and too hard metal fractures when roughly handled. Solid drawn tubes are made of 35-42 tons tensile, with elongation of 15 per cent. in 8 in.

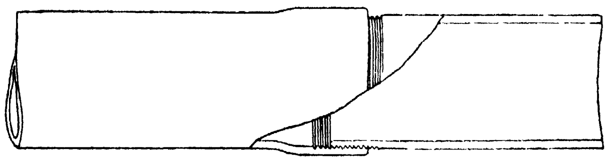
(*g*) Stout thread protectors must be provided for both the collar and screwed ends to avoid damage in transit to the field,



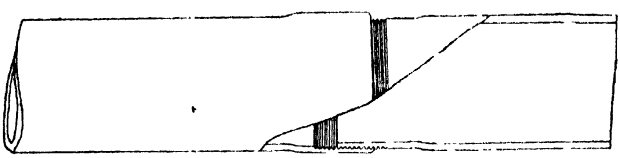
Collared Casing.



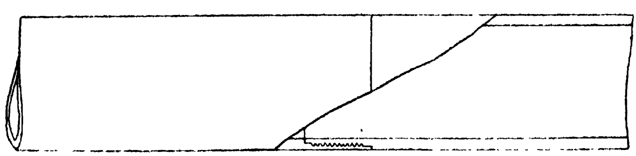
Drive Pipe.



Inserted Joint Casing.



Inserted (Swelled and Cressed) Casing.



Flush Joint Casing (Rarely Used).

Fig. 87.- Types of Tubing for Lining Wells.

and the threads of both collar and screwed ends should be coated with a preservative against corrosion.

(*h*) All tubes must be tested to from 500-1,000 lbs. per square inch, according to size.

Two classes of lining tubes are in use for bore holes, distinguished for convenience by the general classification of *casing* and *drive pipe*. The former have from fourteen to ten threads per inch, with a taper of $\frac{3}{8}$ in. and $\frac{3}{4}$ in. to the foot on diameter according to size and type, and the joints do not meet at the centre. Drive pipe is usually heavier, except for the California type of casing, and is screwed eight threads per inch, with a taper of $1\frac{1}{2}$ per cent. to 3 per cent. on diameter according to size. The ends of tubes are faced and butt in the centre of the collars. The latter class better withstands the rough treatment to which it is often subjected, and is used where heavy driving is necessary to secure the freedom of the column.

Collared casing naturally obstructs the movement of a column of tubing, and for duties where driving can be avoided the objection has been partially overcome by the use of inserted joint casing. Inserted joint casing is of two types, the one swelled and cressed, and the other swelled only, the internal screwing being in the swelled end, and the external screwing on the cressed or parallel end. Tapered threads of eleven and a half and fourteen per inch are customary with 3 per cent. taper. Swelled and cressed tubing suffers the disadvantage that it cannot so easily be repaired by attaching a new collar or re-screwing a damaged end as in socketed pipes. This and the plain inserted type of casing are very largely used in Galicia and Roumania with unqualified satisfaction.

During recent years extensive use has been made of weldless casing of the solid drawn type, which admirably suits oil-field work. Its more extended use has been restricted solely by its higher cost, especially in the larger sizes.

Well casing is usually manufactured and sold in random lengths, otherwise an increased price is demanded. British tubes are made in lengths of from 16-22 ft.; American, 20-25 ft.; but solid drawn tubes may be obtained much longer, 35-40 ft. Operators usually prefer lengths of about 20 ft., owing to the difficulty of handling and placing in alignment for screwing those of greater length. In the standardisation of American casing, the fixing of a series of sizes that will pass freely inside one

another has been kept in view, a common practice when moderately strong casing is necessary being $12\frac{1}{2}$ in., 10 in., $8\frac{1}{4}$ in., $6\frac{5}{8}$ in., $5\frac{3}{16}$ in. nominal internal diameter. This gives an actual reduction in diameter of $7\frac{1}{2}$ in. in four columns, an average of 1.87 in. for each string. The table on p. 415 gives the main properties of standard American common types of casing and drive pipe. Where there are several thicknesses of one nominal sized piping the external diameter is maintained, so that casing elevators and other appliances for handling casing need not be varied in size. The small difference in internal diameter calls for no modification of the tools.

The initial and completed diameter of wells varies greatly. Deep Russian wells are commenced with casing up to 3 ft. 6 in. diameter to ensure a finished size that will admit fair-sized bailers. Diameters of 2 ft. 6 in. are frequent in Roumania, where bailing is the customary means of extracting oil, but in other countries 12-18 in. is a more popular size. When wells are pumped, finishing diameters of from 4-6 in. are ample to permit the insertion of pumps that will ensure the full yield of the well.

Riveted or Stove Pipe Casing.—Where lining tubes of large diameter are required it is customary to use riveted sheet-iron casing. The manufacture of this type of casing has been largely conducted in Roumania, and perfected in the Caucasian oil-fields of Russia, where from 40,000 to 50,000 tons are annually used in sizes from 42 in. downwards. Riveted casing has been made as small as 6 in. in the Russian fields, when all screwed tubes had to be imported against a heavy import duty, but more generally sizes below 12 in. are now of the screwed variety, and in many cases a special type of screwed casing is used running up to 14 in. in diameter.

Russian casing is made by cutting sheets of $\frac{3}{16}$-$\frac{3}{8}$ in. iron into the requisite size, and after punching and counter-sinking the holes on the inner side and rolling into shape, riveting up the vertical lap-jointed seams by a double or treble row of rivets placed zigzag. The tubes are usually made in lengths of 4 ft. 8 in. (2 arsheens), and at one extremity a rolled strip

TABLE XIV.—DIMENSIONS AND WEIGHTS OF ASSORTED AMERICAN CASING AND DRIVE PIPE.

Nominal Internal Diameter.	Diameters in Inches. External.	Diameters in Inches. Internal.	Thickness.	Weight in lbs. per Foot. Plain Ends.	Weight in lbs. per Foot. With Couplings.	Threads per Inch.	Couplings. Diameter.	Couplings. Length.	Couplings. Weight, lbs. per Ft.
				STANDARD CASING.					
12½	13.000	12.482	0.259	35.243	36.500	11½	14.025	6⅛	37.499
10⅝	11.000	10.552	0.224	25.780	26.750	11½	11.911	6⅛	28.536
8¼	8.625	8.191	0.217	19.486	20.000	11½	9.413	5⅛	6.461
6⅝	7.000	6.538	0.231	16.699	17.000	11½	7.664	4⅝	10.225
5$\frac{3}{16}$	5.500	5.192	0.154	8.792	9.000	14	6.078	4⅛	6.200
				DRIVE PIPE.					
12	12.750	12.090	0.330	43.773	45.358	8	13.950	6⅝	47.220
12	12.750	12.000	0.375	49.562	51.067	8	13.950	6⅝	47.220
10	10.750	10.136	0.307	34.240	35.628	8	11.950	6⅝	40.108
10	10.750	10.020	0.365	40.483	41.785	8	11.950	6⅝	40.108
8	8.625	7.981	0.322	28.554	29.303	8	9.588	6⅛	24.343
8	8.625	7.917	0.354	31.270	32.334	8	9.882	6⅛	31.320
6	6.625	6.065	0.280	18.974	19.408	8	7.473	5⅛	13.956
4½	5.000	4.506	0.247	12.538	12.758	8	5.723	4⅛	7.439
				CALIFORNIAN BX CASING (Medium Weights).					
12½	13.000	12.360	0.320	43.335	45.000	10	14.116	8⅛	54.508
10	10.750	9.902	0.424	46.760	48.000	10	11.866	8⅛	45.365
8¼	8.625	7.775	0.425	37.220	38.000	10	9.627	8⅛	33.096
6⅝	7.000	6.214	0.393	27.731	28.000	10	7.698	7⅝	17.943
				CALIFORNIAN DRIVE PIPE.					
4½	5.000	4.506	0.247	12.538	12.850	10	5.686	6⅛	10.734
4½	5.000	4.424	0.288	14.493	15.000	10	5.923	6⅛	14.299
				INSERTED JOINT CASING.					
				Without Couplings.			Length of Joint.		Diameter of Swelled Part.
12½	13.000	12.482	0.259	35.243		11½	2.073		13.384
10⅝	11.000	10.552	0.224	25.780		11½	1.873		11.314
9⅝	10.000	9.582	0.209	21.855		11½	1.773		10.284
8⅝	9.000	8.608	0.196	18.429		11½	1.673		9.258
7¼	7.625	7.263	0.181	14.390		14	1.505		7.877
6⅝	7.000	6.652	0.174	12.685		14	1.442		7.238
5⅝	6.000	5.620	0.190	11.789		11½	1.373		6.246
4¼	4.500	4.216	0.142	6.609		14	1.192		4.674

another has been kept in view, a common practice when moderately strong casing is necessary being $12\frac{1}{2}$ in., 10 in., $8\frac{1}{4}$ in., $6\frac{5}{8}$ in., $5\frac{3}{16}$ in. nominal internal diameter. This gives an actual reduction in diameter of $7\frac{1}{2}$ in. in four columns, an average of 1.87 in. for each string. The table on p. 415 gives the main properties of standard American common types of casing and drive pipe. Where there are several thicknesses of one nominal sized piping the external diameter is maintained, so that casing elevators and other appliances for handling casing need not be varied in size. The small difference in internal diameter calls for no modification of the tools.

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Russian casing is made by cutting sheets of $\frac{3}{16}$-$\frac{3}{8}$ in. iron into the requisite size, and after punching and counter-sinking the holes on the inner side and rolling into shape, riveting up the vertical lap-jointed seams by a double or treble row of rivets placed zigzag. The tubes are usually made in lengths of 4 ft. 8 in. (2 arsheens), and at one extremity a rolled strip

which a corresponding taper wedge block slides. This latter wedge block is connected by a rod to the surface cross bar into which it is screwed with a square thread, the lower end of the rod rotating freely in the wedge block. The suspension rods are just the correct length to allow the cast-iron segment blocks to lie against the collar to be riveted, and by screwing the central spindle in the cross bar the wedge block is drawn upwards, forcing the segments outwards against the inner face of the casing. A few blows from a hammer on the casing where touching the iron blocks ensures perfect contact at all points: then riveting may be commenced.

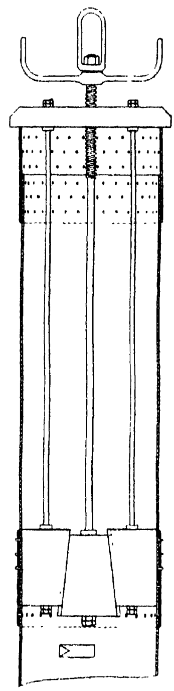


Fig. 89.—Riveting Block. (Inset section of rivet.)

The rivets are specially made from soft iron for the work, as, of course, under oil-field conditions they have to be hammered cold; and at one end they have a V-shaped recess which leaves a sharp circular edge. When the rivets are driven against the block, the fine rim of the iron expands and fills the internally countersunk hole, whilst simultaneously the spare metal on the outside is being hammered into a head by the riveters.

When all the holes are riveted up on the blocks, the central spindle is released, and the blocks turned to a new position. The operation is then repeated, two men usually being employed on each side of the blocks at the same time. If the tubes are connected in longer lengths, the suspension rods and central spindle are replaced by longer ones, and for other sizes of casing suitable cast-iron segment blocks are attached to the apparatus.

Table XV. gives the particulars of riveted lining tubes with 12-in. collars made of $\frac{3}{16}$, $\frac{1}{4}$, and $\frac{5}{16}$ in. iron, as used in the Russian oil-fields.

TABLE XV.—PARTICULARS OF RIVETED LINING TUBES WITH 12-IN. COLLARS.

Diam. of Tube	Size of Iron for Tube.	Size of Iron for Collar.	Tube. Weight in Poods.*			Collar. Weight in Poods.			Total. Weight in Poods			Total Weight in Poods per Sagen.		
			3/16 in.	1/4 in.	5/16 in.	3/16 in.	1/4 in.	5/16 in.	3/16 in.	1/4 in.	5/16 in.	3/16 in.	1/4 in.	5/16 in.
8	56 × 29	12 × 32	2.3	3.1	3.9	0.55	0.73	0.91	2.9	3.8	4.9	4.3	5.7	7.3
10	56 × 35	12 × 38	2.9	3.7	4.7	0.65	0.88	1.10	3.6	4.6	5.8	5.4	6.9	8.7
12	56 × 42	12 × 44	3.4	4.5	5.7	0.76	1.01	1.26	4.2	5.5	7.0	6.3	8.2	10.5
14	56 × 48	12 × 51	3.9	5.2	6.5	0.88	1.17	1.43	4.8	6.4	7.9	7.2	9.6	11.8
16	56 × 54	12 × 57	4.4	5.8	7.2	0.99	1.32	1.65	5.4	7.1	9.0	8.1	10.6	13.5
18	56 × 60	12 × 63	4.9	6.5	8.1	1.09	1.50	1.84	6.0	8.0	9.9	9.0	12.[illegible]	14.8
20	56 × 67	12 × 70	5.4	7.1	9.0	1.20	1.60	2.0	6.6	8.8	11.0	9.9	13.2	16.5
22	56 × 73	12 × 76	5.9	7.9	9.8	1.29	1.70	2.1	7.2	9.6	11.9	10.8	14.4	17.8
24	56 × 79	12 × 83	6.4	8.5	10.7	1.44	1.90	2.4	7.8	10.4	13.1	11.7	15.6	19.6
26	56 × 86	12 × 89	7.0	9.3	11.6	1.53	2.00	2.6	8.5	11.3	14.1	12.7	16.9	21.1
28	56 × 92	12 × 95	7.4	10.0	12.4	1.65	2.2	2.8	9.0	12.2	15.2	13.5	18.3	22.8
30	56 × 98	12 × 101	7.9	10.6	13.2	1.74	2.4	2.9	9.6	13.0	16.1	14.4	19.5	24.1

* 1 pood = 36 English pounds

Sometimes "double" riveted casing is made which really consists of a tube and collar in which the latter is equal in length to the former, but when riveting the two tubes together, one is made to extend about 12-16 in. beyond the other to form a collar to which the next tube can be attached. Table XVI. gives particulars of the sizes of iron, weights, etc., of such double tubes.

TABLE XVI.—PARTICULARS OF DOUBLE RIVETED CASING.

(All weights in poods.)

Diam of Tube.	Size of Iron for Outside Tube.	Size of Iron for Inside Tube.	Weight of Outside Tube.		Weight of Inside Tube.		Total Weight.		Weight per Sagen.	
			$\frac{3}{16}$ in.	$\frac{1}{4}$ in.	$\frac{3}{16}$ in.	$\frac{1}{4}$ in.	$\frac{3}{16}$ in.	$\frac{1}{4}$ in.	$\frac{3}{16}$ in.	$\frac{1}{4}$ in.
Inches.	Inches.	Inches.								
12	56×43	56×41	3.5	4.6	3.3	4.4	6.8	9.0	10.2	13.5
14	56×49	56×47	4.0	5.3	3.8	5.1	7.8	10.4	11.7	15.6
16	56×55	56×53	4.5	5.9	4.3	5.7	8.8	11.6	13.2	17.4
18	56×61	56×59	5.0	6.6	4.8	6.4	9.8	13.0	14.7	19.5
20	56×68	56×66	5.5	7.3	5.3	7.1	10.8	14.4	16.2	21.6
22	56×74	56×72	6.0	8.0	5.8	7.8	11.8	15.8	17.7	23.7

The Roumanian riveted casing ranges from 16-24 in. in diameter, and is made in $\frac{3}{16}$-$\frac{1}{4}$ in. iron. Some of the casing is made with the vertical seam butting and held by an outside strap riveted on. Welded casing is now often used, a welded collar alone being attached by riveting.

Casing Shoes.—The base of the bottom joint of a column of casing is generally protected by a steel shoe with cutting edge, thus preserving the casing from damage and enabling obstructions to be passed. For light shallow duties a turned welded steel collar with case-hardened cutting edge is either screwed or shrunk on to the casing, and sometimes additionally secured by riveting in place. For heavier work solid drawn steel shoes such as illustrated in Fig. 90 are used, the larger, heavier type being employed in difficult inclined strata where severe strains are thrown on the shoe in passing obstructions of hard and often steeply inclined beds. Sometimes a shoe with serrated

edges, as Fig. 90, is preferred for more effectively shearing side boulders or other impediments. The longer shoes always afford greater facilities for excluding upper water by being driven firmly into an unreamed impervious stratum struck at a convenient point.

Methods of Ensuring Freedom of Casing.—Until recent years bore holes were drilled by tools passing freely in the lining

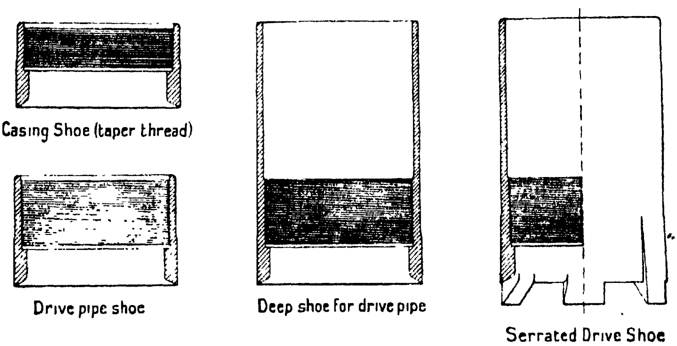


Fig. 90.—Types of Shoes.

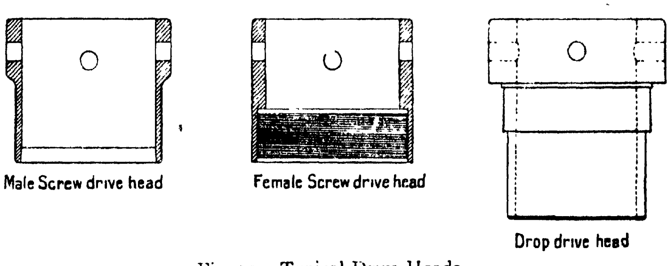


Fig. 91.—Typical Drive Heads.

tubes, thus making a hole rather less in diameter than the internal diameter of casing, and reliance was placed entirely upon driving the casing, compelling the shoe to cut out a hole to the desired diameter. This unscientific work is becoming less and less practised, but at times a few judiciously applied blows will release a column of tubes obstructed by some detached material. The usual drive heads are illustrated in Fig. 91. Objection to the use of the middle design lies in the fact that the

collars are generally screwed on to the casing by power in the shops before delivery, and their removal is difficult and takes time. The sliding of the column on to the top of the clamp would also entail much delay and possible danger in replacing the drive head by the collar. If a column of casing only requires a slight tap to drive it past a hard streak, there is no necessity to attach a drive head. In place of the drive head a pair of large wooden drive clamps are attached to the auger stem directly under the iron drive clamps: these wooden clamps are to protect the collar of the drive pipe.

With the hollow drive heads a monkey may be used, guided by a spindle passing through the head, but in cable drilling it is usual to attach a heavy pair of clamps to the drill stem, which is then operated as in "spudding," the force of the blow being determined by the speed of running and length of stroke. When drop monkeys are used any simple contrivance is fixed up which will enable the monkey to be released after being raised to a height determined by circumstances. The monkeys may be iron-bound hard wood or cast-iron blocks. Sometimes it is preferable to press casing instead of driving, and such is always the case when riveted casing is used. Fig. 92 shows an appliance for pressing tubes. Hydraulic or screw jacks placed between a suitable disc head and anchored beam will achieve the same end.

A column of tubes is usually kept free in caving ground by repeated lifting and lowering on the pulley blocks every time a new length of tubing is inserted, but when progress is slow the same performance is undertaken several times daily when cleaning out the hole. Release of a gripped column may sometimes be effected by pumping water into the well until the pressure causes it to rise outside the column, thereby loosening the accumulated sediment. At other times it may be necessary to raise a number of lengths before complete freedom is obtained and work may be safely resumed.

If a column is stuck tightly it may possibly be loosened up by filling the hole with water, and then taking a strain on the column with hydraulic jacks. After being left so for two or three days, it may often be pulled with ease.

So much depends upon the maintenance of freedom of a column of tubes in drilling that means for securing this end acquire an importance that is only appreciated by those who have conducted drilling in strata of a caving nature like those in the

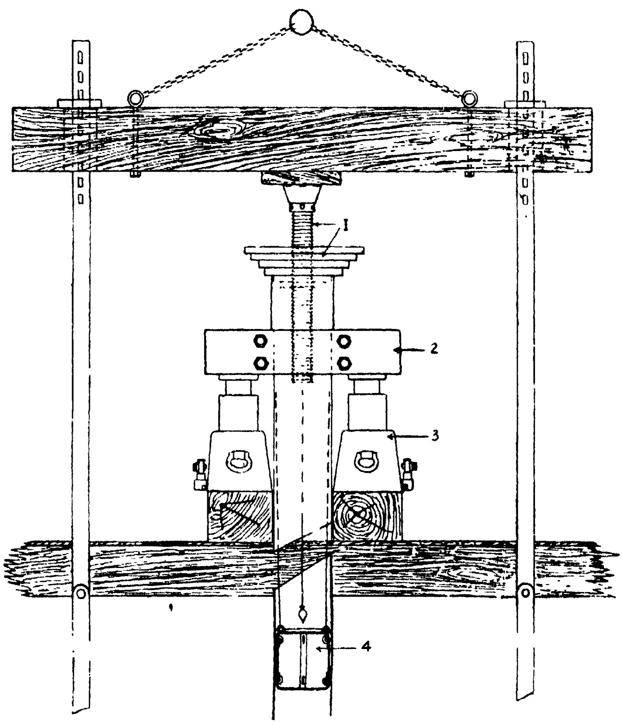


Fig. 92.—Sketch showing Arrangement for Pressing Casing, Jacking Casing, and Centring Apparatus.

1. Screw with swivel head working in C.I. disc that sits on casing collar.
2. W.I. clamps for jacking.
3. Hydraulic jacks.
4. Centring device, with plumb bob on top.

oil-fields of Russia, Roumania, California, and Burma. Days and weeks may be passed in patiently cleaning out cavings that are put in motion each time the column is moved, with the absolute knowledge that failure to overcome the trouble and pass the troublesome spot will endanger the work already performed. To

the need for keeping casing free is largely attributable the customary continuance of night work in oil drilling, prolonged inactivity nearly always endangering the column in certain strata.

Mud flush circulation in the presence of rotary or cable tools has done much to reduce the troubles alluded to. Not merely does mud exercise a less solvent action on sedimentary beds, but its higher density causes it to better sustain the walls of the well if they are inclined to cave. The lubricating property of puddled clays must not be overlooked in this connection, whilst some actual plastering of the walls may occur when the casing is put in motion. Notwithstanding the use of mud, it is upon skilful manipulation of a column of casing that reliance is still largely placed for the realisation of a fair sized hole at depth without starting with too large an initial diameter.

Automatically operated hydraulic jacks have been used to some extent in a shaft beneath the derrick floor, the casing by this means being alternately raised and allowed to fall back during the progress of drilling. There are, however, so many objections to the installation of plant in a shaft that the process has never become popular.

What is known as the "*swinging spider*" has been successfully introduced into California, where caving difficulties greatly hampered the insertion and freedom of casing in efforts to reach deep oil sources. With the aid of this apparatus whole lengths of casing can be inserted when carrying the casing instead of introducing a succession of short nipples. A shaft about 8 ft. square is sunk beneath the derrick floor, and lined to a depth of 21 ft., and at the base are fixed two concrete or hard wood sills, wide enough apart to allow the largest casing used to pass between, upon which sills the lower supporting spider rests. The cellar is timbered round the sides and base, and a ladder is fixed for the descent of attendants.

When commencing a well, or when not in use, the swinging spider is left reclining against the side of the derrick till required. The lower spider in the shaft is allowed to take the weight of the column when lowered, whilst the elevator is replaced by the so-called swinging spider, consisting of two long straps that pass on either side of the walking beam, and act as the suspension medium

between the travelling block and the swinging spider. When lowering or raising the tools or cleaning out the holes the slips are released, the spider lowered, and the suspension rods are allowed to rest against the wall of the cellar, but when the tools are again slung from the walking beam the spider is raised, the slips inserted, and the weight thrown on the block. Some spiders are fitted with rope-sheaves and suspended by steel wire lines.

By this means it is possible to manipulate casing at will, and move it with the aid of the calf wheel as frequently as is found advisable by experience to ensure the freedom of the column. During the operation of coupling a new length of casing, the slips are placed in the lower stationary spider to support the column till a new length is screwed on and the swinging spider again attached (see Fig. 51, Chapter VII.).

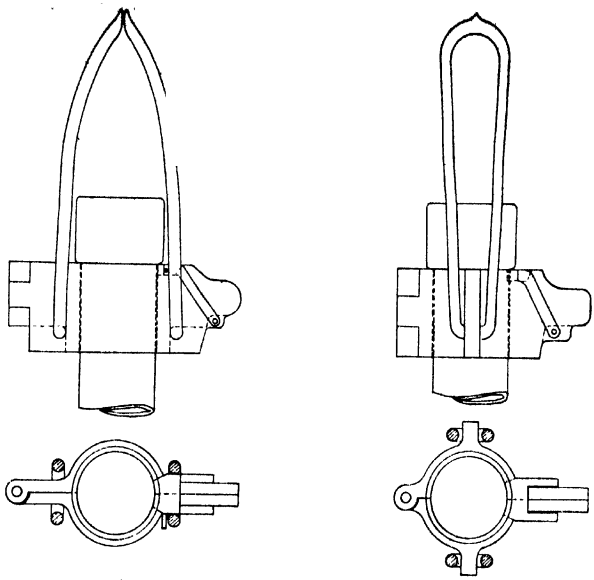
The precaution should be taken of resting the clamps supporting each column of casing on wooden blocks, which prevent each string sustaining the full weight of the smaller string should it slip.

Casing Clamps and Elevators.—Light columns of socketed tubes are suspended and handled by simple wrought-iron or wooden clamps, but heavier, longer columns demanding frequent manipulation require fittings more easily and quickly handled. What are commonly known as elevators are illustrated in Fig. 93.

Fig. 93, A, illustrates a pattern of elevator that can only be opened up when the suspension links are lowered. The class illustrated in Fig. 93, B, can be opened without lowering the links and is more useful where it may be necessary to disconnect or connect high up in the derrick, as in rotary drilling. Both types slide freely over the casing and have a safety locking device which prevents them being opened whilst the collar rests on the upper edge.

Flush or inserted jointed tubes are supported in the derrick by wedge rings or spiders, such as shown in Fig. 94. These spiders are used when jacking up columns of casing, and are of very heavy construction.

Cutting and Removing Casing.—When a well has been completed, and several columns of casing have been used in its construction, it is obviously to the proprietor's advantage to recover as much as possible. If no service further than



A B

Fig. 93.—Casing Elevators.

A. Type that can only be opened by lowering the links.
B. ,, ,, be opened without ,, ,,

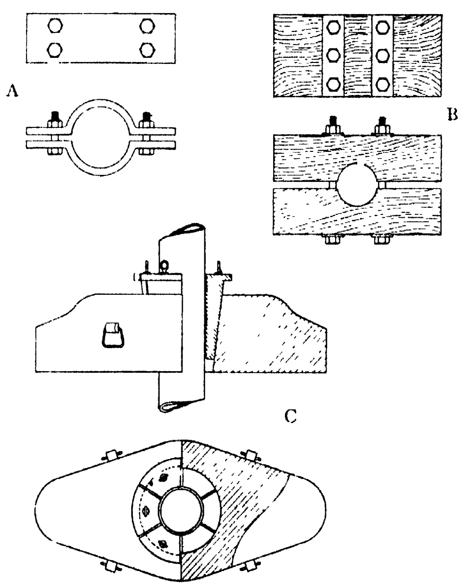


Fig. 94.—Casing Clamps and Spider.

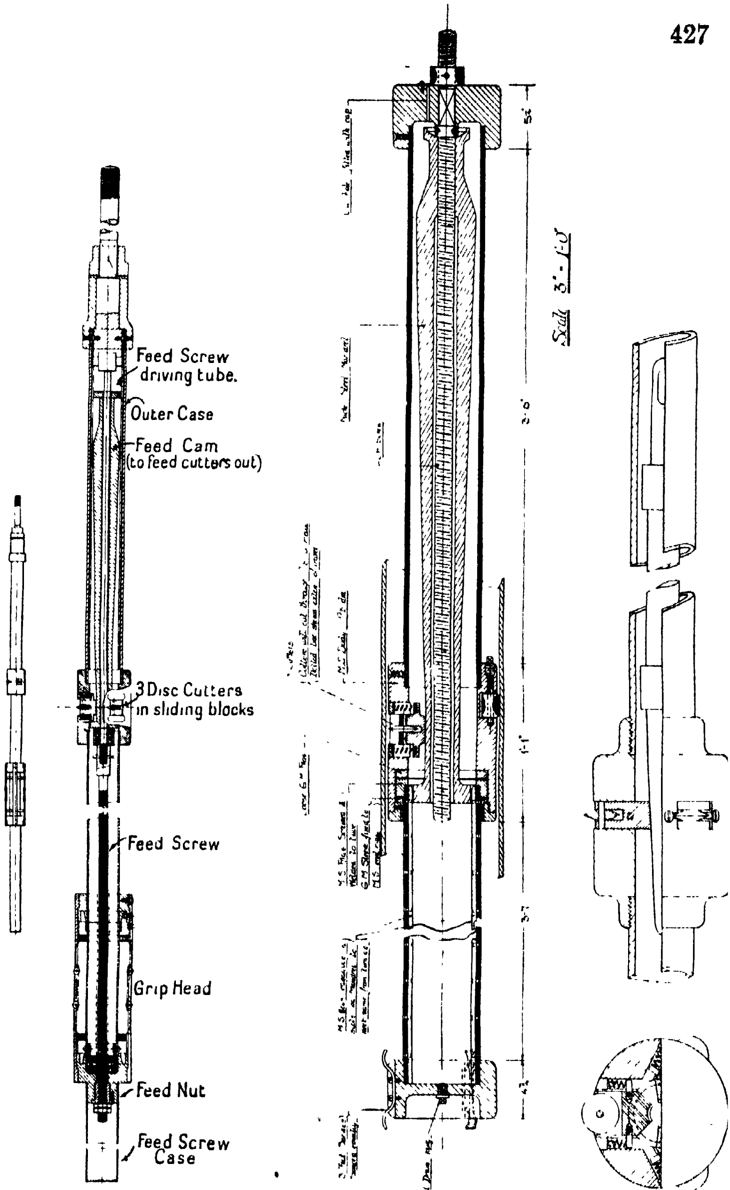
A. Iron Clamps. B. Wooden Clamps. C. Spider or Wedge Block.

supporting the wall of the bore hole until the completion of the well has to be performed, all the casing, with the exception of the last column, should be jacked up for future use in other wells. Unfortunately, in many cases the casing becomes firmly gripped and cannot be wholly recovered, under which circumstances the tubes can be cut and removed from the point where they do not come into contact with the side of the well, but are protected telescopically by the preceding larger column. The tubes are cut by lowering a special form of cutter on rods or tubing to the desired position, the rotation of the rods or tubes at the surface causing both the rotation and expansion of the cutters below.

Columns of casing are sometimes arranged for severance at some projected point, prior to insertion, thus removing the necessity of using cutting appliances. This is done by leaving a well-lubricated joint less tightly screwed up than the remainder, or providing a left-handed thread at the desired point. Even under normal conditions of work where the joints have been consistently screwed up, it is sometimes possible to unscrew a joint somewhere near the desired point. This is accomplished by unscrewing after taking the weight of the column on blocks or jacks. According to the power applied, there is always one joint on which friction is less than the others, that is where the weight of casing and tension applied are equal, this consequently being the easiest joint to disconnect if all are equally screwed up. Unscrewing under high tension generally assures the severance of a column near its base.

The cheaper tube cutters of inferior types, of which C (Fig. 95) is an illustration, are not positive in action, but the more perfect tools are positive and absolutely reliable in practice.

A serviceable type of tube cutter which is largely used in the Russian oil-fields for cutting riveted lap-jointed casing where the work is somewhat severe in having irregular cutting and two thicknesses of metal to cut through at the point of lapping, is represented by A and B (Fig. 95). A combined guide and grip head, holding a screw nut in which the spindle rotates, is kept from revolving when the rest of the apparatus is rotated, by spring wheels which catch against the vertical lap joint of the casing. When a welded casing is used this guide is kept stationary by springs



A B C

Fig. 95.—Tube Cutters.

A. Positive Acting Tube Cutter. B. Positive Acting Tube Cutter with Internal Feed Screw. C. Cutter with Weighted Mandrel.

of a somewhat different design. In the body of the apparatus are three sliding jaws fitted with horizontally placed steel roller cutters, which are kept back against the centre spindle by small springs. When the rods at the surface are turned, the whole apparatus revolves with the exception of the guide, and at the same time the central tapered cone spindle is drawn downwards by its lower threaded portion working in the nut in the guide. Consequently, as the tool is rotated, the cutters are slowly forced outward until the maximum diameter of the tapered spindle is reached and the tube has been entirely severed, after which, by continuing the rotation longer, a recess in the spindle allows the jaws to return to their original position. The exact point when the operation is completed is known by counting the number of revolutions.

Both of the above cutters suffer from the objection that their efficient employment is restricted to those cases where the tubing has suffered no distortion of shape, but in practice the tubing is sometimes slightly oval in the vicinity of the projected cut. This difficulty has been surmounted by an hydraulic cutter. It is the most perfect instrument of its class that has yet been introduced. By its use it is possible to completely cut the casing, even if it is squeezed into an oval form at the point of cutting.

In the head of the tool is arranged a circular clutch with ratchet teeth, so that if the upper half of the clutch be rotated in one direction by turning round the boring rod, the ratchet teeth slip over each other, and the lower half remains stationary; while if the upper half be rotated in the reverse direction, the ratchet teeth engage, and the lower half is also rotated.

The second portion of the tool consists of a hollow cylinder connected to the lower half of the clutch, in which works a solid rod attached to the upper half. This second portion is provided with external guides to centre it in the tube. Below this comes the cutter proper, consisting of a removable cylindrical body, in which are three or more horizontal cylinders arranged radially. In these cylinders, which are in communication with the pressure cylinder above, there work three or more hollow pistons open at one end, and having circular steel cutting discs mounted in them so as to

project beyond the cylindrical body. At the bottom is another set of guides and gripping rollers.

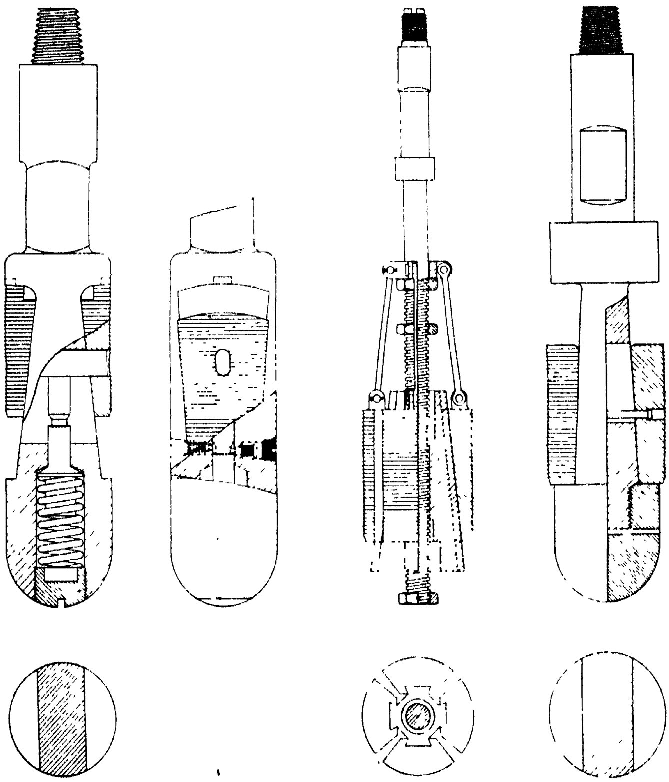
The pressure cylinder having been filled with liquid, which is preferably the same as that in the bore hole, and the cutter pistons being withdrawn into the cylindrical body, the tool is lowered down to the requisite depth. The boring rods are then rotated in such a direction that the ratchet teeth slip; and the lower part of the tool remaining stationary, the solid rod will be forced down into the liquid in the pressure cylinder, and consequently the cutter pistons will be forced outwards, until the cutting discs bear against the inside of the tube to be cut. On then reversing the direction of rotation, the ratchet teeth engage with each other, and the whole tool is rotated in the tube, the cutters doing their work. When the cut has been completed, the solid rod is forced still further down into the pressure cylinder, and the whole tool can be withdrawn from the bore hole.

Another form of casing cutter of American design has a body very similar to that of others in respect to the cutters, but it is lowered into the well on tubing, and the cutters are pressed outwards by a weighted, tapered spindle, which is suspended by a wire rope inside the tubing. The tapered spindle coming into contact with the inner ends of the cutter holders, forces them outwards when weight is thrown on to the spindle by slackening the rope. C, Fig. 95, shows this type.

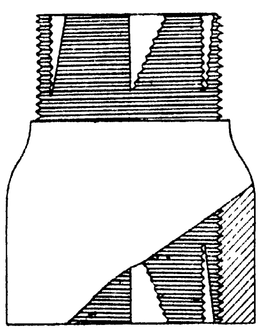
When cutting casing, the column should be kept in a state of light tension by jacks, so that separation takes place when the severance is nearly completed, thereby preventing the breakage of the cutters through the weight of the cut tubes being thrown upon them.

Casing is sometimes severed in wells by exploding a charge of explosive at the desired point, and at other times the casing is split with a slitter at the collar, so that a pull on the column causes the threaded portion to collapse.

Recovering Lost Casing.—In well boring a column of casing sometimes falls through carelessness or accident in lowering, or parts in the well through a faulty socket or screwed end; it may also become severed through damage. A common class of appliances for recovering casing that cannot be reached from the surface is



A B C



A. Trip Spear, Henderson's type, for use on Cable.

B. Positive Acting Spear for use on Rods.

C. Bull-Dog Type which cannot be released.

D. Tempered Screwed Nipple and Die for fishing Casing.

D

Fig. 96.—Casing Spears.

known as a casing lifter or spear. These tools are often used in assisting to free tight columns of casing by taking a hold deep down in the well. The simplest form of tool is shown in Fig. 96, C but its employment must be confined to columns known to be free as it cannot be released when once a hold has been established.

An exceedingly serviceable and safe tool is illustrated in Fig. 96, B, where all the main features are self-apparent. The dogs are expanded by rotating the rods or tubing upon which the tool is lowered, and they may be released by a reverse movement.

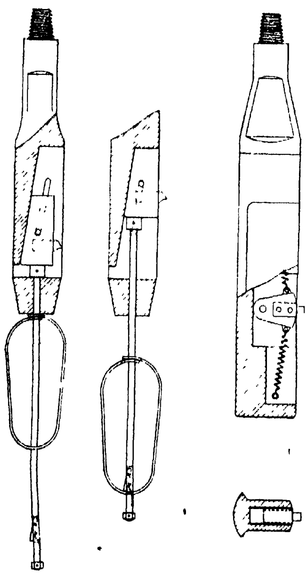
Cable drillers largely rely upon a type of spear which is lowered on a wire rope and operated by long-stroke fishing jars. Great ingenuity has been displayed in the design of American tools for this work, and whilst lacking the obvious advantages attached to the use of rods, they are in general and popular use. These American spears rely upon a trip movement which frees the dogs or slips when an upward pull is applied. Henderson's spear, illustrated in Fig. 96, A, is an example of the class. The tool is set by forcing down the slips till a connecting bar, loosely connected to the slips, forces a central spindle against a powerful spring into a position where a spring catch lightly engages in a groove in the spindle and keeps it under the pressure of the spring in that position. The slips are then free to slide on the tapered body, and during insertion they rise through friction with the sides of the casing to a point where the descent is free, but at any moment a grip can be taken by lifting the rope or rods on which the tool is being lowered. The act of lifting causes the central spindle to come into contact with the cross bar, thus releasing the lightly held spring catch. Should it be desired to release the spear, a few downward strokes of the jars releases the pressure on the casing, and the central spindle pushes the slips upwards beyond the possible point of further grip.

The delicacy of the trip is one of the objections to its use, a slight resistance in its descent, such as might be occasioned by a collar or small distortion of the casing, causing the spear to trip, thus rendering it necessary to raise it to the surface for resetting.

Lost casing may be recovered by lowering on a string of casing a steel screwed nipple or die (Fig. 96, D). When a firm grip has been established, jarring is commenced, and success sometimes

rewards efforts after many hours and even days of constant hammering. A glorified bell socket, such as illustrated in Fig. 72, H would prove effective.

Perforating, Punching, and Slitting Casing.—"Frozen" (using a driller's expression) casing can sometimes be recovered by perforating or slitting the casing at a point where sand or other caving material is firmly packed around. It is also necessary at times to make perforations to allow higher and excluded fluids to enter the



A. Casing Slitter in condition when being lowered and cutters out of action.

B. Casing Slitter when adjusted for slitting casing on being jarred downwards. The cutter is set by first raising tool to allow the slip to catch beneath the catch on spindle, and then lowering. On raising, the cutter is again thrown out of action.

C. Perforator that punches a hole at each ascent and descent of the tool.

A B C

Fig. 97.—Casing Slitter and Perforator.

well. Holes may be punched at selected points by using the tool shown in Fig. 97, C. This is lowered on rods or tubes, and a perforation is made at each ascent or descent of the tool. The punch may be round, square, or of other shape, provided its design ensures clearance and release after perforation. Clean perforations may not be possible with such a tool, as there is no hard body to act as a die, but they equally well answer their purpose.

A more complex and perfect tool is that shown in Fig. 98,

whereby holes may be drilled in the casing and a clean disc be abstracted. The rods or tubes upon which it is lowered to the desired point are rotated by a light steel rope driven from some part of the boring rig.

The tool consists of a machined C.I. body suspended by ball-bearings, to minimise friction, from a column of tubes or rods Two bevel wheels in the upper part transmit motion from the rods to a train of spur wheels mounted on successive spindles in the body. The second spindle carries an annular cutter or milling tool which, by the aid of a feather in the gear wheel, permits its lateral movement whilst being rotated. Spindle three acts as a base for a fulcrum of the feeding lever, as well as an axis for one of the train of wheels which operates the lowest screwed spindle at a low speed. Attached to the base of the apparatus is a gripping device for keeping the tool from rotating. On its upper edge is a ratchet that is locked during working by a small spindle held into a recess by a light spring. When the rods are rotated to the right the cutter rotates, and is fed forward by the feed screw on the lowest spindle. On reversing the motion of the rods, after the work is accomplished, the lower extension of the feed nut strikes the lever of the grip device, when the milling cutter is drawn back inside the body of the tool, and raises the pin which alone prevented the ratchet operating. The

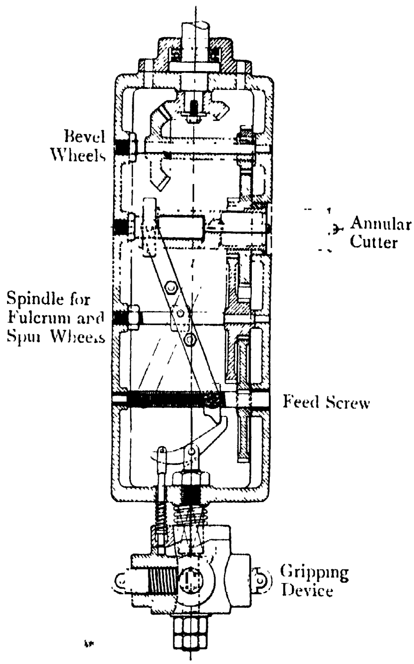
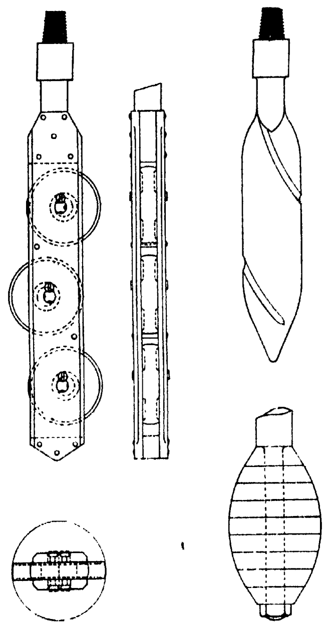


Fig. 98.—Casing Perforator Designed to Pierce One or More Strings of Casing.

whole tool can then be revolved to the left and advanced a tooth, thereby enabling a second hole to be drilled at another position in the same horizontal plane.

Tools of the above description can be designed to perforate several columns of casing at one operation, a procedure quite impossible with all forms of punches. Likewise holes can be drilled with these tools through annular rings of cement.



A B C

A. Adjustable Roller Swedge.

B. Common form of Drift, wherein the body is fluted to allow liquid to pass in its descent or ascent.

C. Swedge with adjustable discs. By adding additional larger discs to the middle of the spindle the diameter is increased. The discs are usually grooved to enable the passage of the tool in liquid.

Fig. 99.—Casing Swedges or Drifts.

Vertical perforations or slits may be made in casing by employing a tool such as that shown in Fig. 97, A.

Repairing Damaged Casing.—Lining tubes frequently get bulged or pressed oval by unequal lateral pressure, thus preventing the descent of drilling tools. If no fracture has been sustained, and the removal of the casing is a long and dangerous procedure, such damage can generally be repaired by driving swedges or drifts past the faulty spot, the steel bodies being fluted to allow of their passage through liquid. Fig. 99, B and C, shows varieties that can

be operated from rods or cable with the interposition of a set of jars, or a free fall to give a release blow after its descent. That shown in Fig. 99, C, can be adjusted by the addition of discs to suit a number of sizes.

A better type, which is less severe in its treatment of the casing, is shown in Fig. 99, A, where three rollers rotate on spindles excentrically mounted. The instrument is lowered on rods or tubing after being adjusted for the desired diameter, and whilst being raised and lowered through the collapsed spot it is rotated to equalise its action. As progress is made the tool is raised, the rollers set out, and the operation repeated till the full diameter is reached.

Separate rollers are kept for different sizes of casing within certain limits allowed by the strength of the body.

Testing Verticality.—Absolute verticality of the well in the initial stage of operations is essential, and a guide pipe or conductor is generally carefully set vertically to secure this end. When a depth of from 100-200 ft. is reached a test is often made, especially in wells of large diameter, to ascertain that all is right, and for this purpose some such apparatus as that shown in Fig. 92 is used. It consists of two discs separated by rods and held central in the tube by spring roller guides. On the upper surface of the top disc is a layer of some plastic substance which will readily retain an impression. When this apparatus has been inserted to the desired depth on light lines, a plumbob is lowered on a cord from the surface over a pulley set at the centre of the tubes to near the disc, allowed to steady itself, and then gently lowered to imprint a dot on the disc. The location of this impression indicates any deviation of the bore hole.

Any departure from the vertical is intimated by lack of freedom of movement of the column of tubes when not obviously attributable to cavings, and to a less free movement of the tools when the hole is clean. Deflection is remedied by lifting the tubes to a point where their vertical and rotary movement is free, filling up the faulty hole with pieces of rock, and cautiously re-drilling.

A beam of light can sometimes be projected into the casing by a pair of mirrors adjusted to give the proper degree of reflec-

tion, when deviation can be observed if the well is not too deep. It is also a common practice to lower several lengths of casing only slightly less than the diameter of the well, when lack of freedom indicates curvature, provided tools rotate freely to the bottom. A long bailer is sometimes used for this purpose.

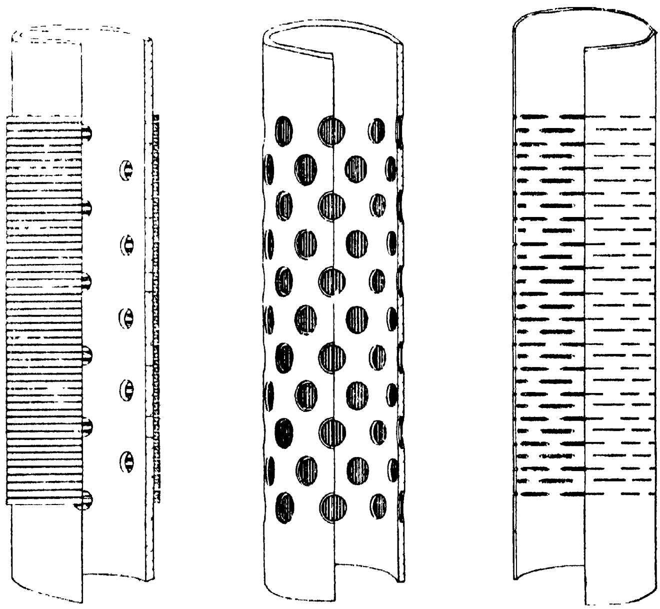
Sand Screens or Strainers.—The greatly enhanced cost of extracting oil contaminated with sand has led to the introduction of various contrivances for effecting its separation. Suspended sand cuts away valves and plungers of pumps so rapidly that their constant removal and repair entail a serious expense, yet where oil exists in loose sands, or sandstones that readily disintegrate, the problem is not easy. Various types of pumps have been designed to diminish the wear and tear occasioned by sand, but naturally the source of the trouble should be attacked in preference to seeking a partial remedy. Trouble is not confined to the excessive destruction of plant, for the sand accumulates in the wells and impedes the free admission of oil, entailing periodical cleaning of the well to ensure the maximum yield of oil.

Sand screens were invented to solve the above described difficulties. There are several forms in the market, and their employment has been attended with signal success in some fields of the United States. The earlier type consisted of brass cylinders pierced horizontally at close intervals with fine slots, the internal edges being chamfered, leaving a fine outside edge (see Fig. 100). Screens were attached to the column of tubes and immersed in the sand. Fine particles of sand at first enter, but in the course of a few days the larger grains pack themselves around the screen in such a way that they create a natural filtering medium, and hold back the finer material.

Cheaper, stronger, and more effective screens were subsequently introduced, consisting of a specially rolled wire which could be tightly wrapped round a perforated piece of ordinary casing, and soldered at intervals (see Fig. 100). Any desired fineness of slot could be made to suit the grade of sand encountered in the wells.

The employment of sand screens is naturally restricted to certain conditions, and their indiscriminate use may involve various losses of production. The presence of high gas pressures will

cause a sand-blast action which will cut screens to pieces in a few days, and particles of clay, if present, will quickly plug the fine orifices and render them ineffective. One representative case could be alluded to where a sand screen had been set under the author's notice and the production gradually declined to nil. It was quite clear that the oil sand was not exhausted, and the known occurrence of much clay with the sand suggested that as the possible cause.



Wire Wound. Inserted Slotted Discs. Milled Slots.

Fig. 100.—Sand Screens.

On withdrawing the screen, oil and sand rushed into the well, and the well flowed vigorously at intervals for some time, yielding about 15 tons (105 barrels) daily.

Whilst the judicious use of sand screens may be very beneficial in special cases, their use is often a doubtful blessing. Dense asphaltic oils impregnating loose sands do not flow readily, and the best yields are obtained by inducing a movement of sand, and encouraging around the base of the well a region of diminished density into which oil may percolate from the surrounding strata.

The cost incurred and time occupied in removing the sand may be irritating, but the subsequent higher and more sustained yields will well compensate for patience in the early stages.

Wells yielding light density oils of no great viscosity can be treated with sand screens for pumping if the sands are troublesome,

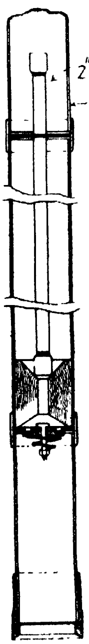


Fig. 101.
Wash Plug.

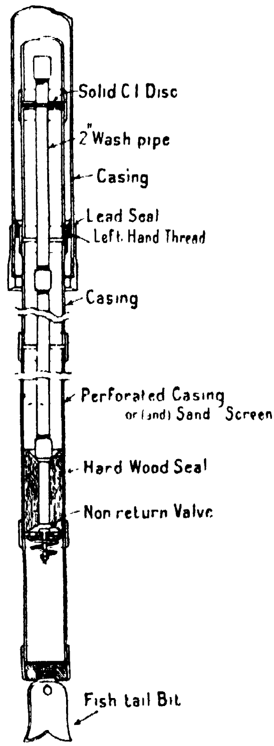


Fig. 102.—Method of Flushing in and Setting Sand Screen.

but even under these circumstances they may prove prejudicial and a source of eventual loss. Few operators in Roumania or Baku would deny the loss wells would sustain by any device to restrain the inflow of sand, at least in the initial period of their productive lives. It is the wells that yield most sand that are usually the largest eventual producers.

The McIvoy wireless well strainer is constructed by the insertion

of slotted metallic discs in lengths of perforated pipe. The disc may be slotted to any desired gauge, and it is claimed that they are thus afforded a protection, and given a strength unattainable by other varieties of screens.

Screens are inserted in loose sands by means of a washing plug that enables them to be washed to their destination and set. A typical wash plug is shown in Fig. 101, where it will be seen that a back-pressure valve is fixed between the shoe and the screen, and an inner pipe is arranged to cause the flow of water or mud beneath the shoe till set. After lowering into position the wash tube is raised till a collar comes in contact with the cast-iron disc, when by recommencing circulation the screen can be washed out internally prior to its final abandonment. Other equally good arrangements will suggest themselves to any engineer.

Fig. 102 shows an arrangement for washing down and setting a sand screen when the material is not readily cleared. A fish-tail flush bit is attached to a strip of casing below the screen, and at a point above the screen, sufficiently high to be inside the shoe of the preceding column, a left-handed thread is provided which enables the upper part of the casing to be unscrewed and removed at will. A diaphragm or disc at a joint above the left-handed thread enables the sand screen to be flushed clean after insertion, by simply raising the 2-in. wash tubes till the lower collar is in contact with the disc, the flush water then being able to pass through the perforations of the screen. After removal of the casing the lead seal may be expanded and driven into the space between the upper part of the screen or tube and the preceding column of tubes, to prevent sand finding admission to the interior of the screen through this channel.

CHAPTER IX.

EXCLUSION OF WATER FROM OIL WELLS.

Injurious Effect of Water in Petroleum Fields—Exclusion of Water by Casing—Packers—Cementing Process of Excluding Water.

Injurious Effect of Water in Petroleum Fields.—There are few oil-fields where water-bearing beds are not found dispersed amidst the oil-bearing strata, or to which water does not find admission, in some quantity, when the beds have been disturbed by numerous bore holes and by the abstraction of great volumes of petroleum. Time after time oil-fields of great promise have been abandoned after the expenditure of fortunes on fruitless attempts to check the apparently almost limitless volumes of water which entered the wells and displaced the petroleum as soon as its extraction was commenced.

The location of water-bearing strata can usually only be ascertained by direct experiment, and the underground movement of water is influenced by numerous fault planes which frequently traverse oil strata where they have been folded and tilted into inclined positions. As the great petroleum supplies of the world are largely confined to porous sands, which lie intercalated between beds of clay or shales, it follows that any sandy layer not impregnated with petroleum will most likely be charged with water. In practice such proves to be usually the case, and unless fairly thick impervious seams of clay separate the water from oil-bearing sands, much difficulty will be found in its exclusion from the latter.

In the United States there are examples of this in the flooding by salt water of Humble Pool, Texas, and of the reluctant abandonment of Batson Prairie, Texas, after the early wells had given so much promise, and from which a production of 1,450,000 tons of oil was obtained in the year 1904; and in Russia there is the abandonment of Berekei, where pioneer wells flowed for months at the rate of 80 tons of oil daily, and led to considerable activity in the district, but where nearly all wells were subsequently flooded

by flows of hot sulphurous water after the oil was struck. Zabrat, a district of the Baku oil-fields, although proved by isolated flowing wells to contain great quantities of petroleum, was practically abandoned owing to the impossibility of excluding the water which permeates many of the intermediate strata, and floods the wells as soon as they are bailed.

In Texas and Louisiana thick beds of water sand have to be passed before penetrating the oil series, and unless the water is totally excluded, the wells are valueless. Many of the original wells in parts of the Baku oil-fields flowed water at a shallow depth, whilst in the western part of the Grosny field of Russia, a large proportion of the wells penetrate a stratum which flows hot sulphurous water in immense volumes, although good supplies of petroleum are found beneath when the water is isolated. Some of the Californian oil-fields have been almost ruined by admitted water after the reduction of gas pressure.

When an oil source is struck beneath a water-bearing stratum a moderate production of oil may be maintained for a while, even if the water is imperfectly excluded by the casing on account of the pressure of the oil, but as soon as the gas pressure diminishes, and the natural level of oil falls below that due to the head of the water, the latter enters the well and mingles with the oil. For a while an emulsified mixture of oil and water may be raised, but as the water increases in volume and cuts a passage behind the casing, the oil is steadily replaced, and an increasing volume of water at length totally excludes the oil from the well, although the gas may continue to escape. As a rule the entrance of water has then proceeded too long to allow of any effectual measures for its exclusion, such as might have been undertaken when the well was first completed.

The loss of a single well through negligence is not a matter of serious concern to any one but the proprietor, but unfortunately the evil consequences of such work are not confined to the single well, as, with the partial exhaustion of the oil, water flows into the oil stratum, mingles readily with the oil, and on account of its less viscous character the mixture readily finds a channel to points where oil is being extracted. More cautious operators who have expended time and money in excluding water find it entering

their wells, and subsequently they are compelled to abandon them on the total displacement of oil by water. Often the innocent sufferer is unaware of the origin of the water, and in any case he is obviously unable to undertake any measures that would reach the seat of the trouble.

It is often an exceedingly difficult and costly matter to prove the source of water that is observed in increasing quantities in wells, and for this reason there is a disposition in oil-field centres to form local boards of reputable operators who sit in judgment on important cases. Sometimes these bodies are authorised to conduct investigations, and enforce or direct remedies at the expense of a fund subscribed by the community. Such committees would have proved more popular but for the suspicion that powerful interests might sway unfair decisions that imposed insupportable burdens upon small operators. Under the guidance of an independent, disinterested president such dangers should seem remote.

Water intrusions may result from a variety of causes not immediately realised. Casing may fracture or suffer corrosion in wells, and so admit previously excluded waters; or a perfect shut-off may become defective. Occasionally a landslide may cause water to enter partially exhausted oil sand through the medium of slip planes, formerly sealed. This is of frequent occurrence in oil-fields where great quantities of sand are abstracted, thus removing hanging wall support; and dozens of wells may simultaneously develop water in great quantities, or the oil be replaced entirely by water. A problem of this kind assumes great importance, as the consequences are serious. Such an event caused considerable consternation in one section of the Tustanowice oil-field of Galicia in 1913.

Analyses of well water might aid in the determination of the source of water troubles at times, but this involves special knowledge and careful selection of water samples, such as is rarely undertaken. The author has conducted experiments with fluorescein and other colouring matter to discover the relationship of underground waters, but with inconclusive results. Some consideration was likewise given by the author to the application of electricity for locating deep-seated waters, but the well casings

constitute such good conductors for electricity that the task appeared hopeless.

In some oil-fields the presence of water is given an unnecessary significance, and quite needless operations are undertaken to effect the exclusion of harmless, and, perhaps, beneficial supplies of water. When strata have slight inclinations only, and fractured zones are rare, sand lenticles of restricted dimensions can be quickly exhausted, a few days' heavy pumping or bailing often reducing the inflow of water to insignificant quantities. Wells yielding mixed oil and water, with the latter predominating, often have the proportion reversed in a few months, and thence onwards display a decreasing percentage of water.

In many fields certain legislation has been invoked to enforce operators to adopt measures of safety involving the welfare of the whole district, but this can naturally only be of a limited description as subterranean movements of water are irregular and influenced by local structural features with which no one is acquainted. Measures of safety, too, may be so imperfectly executed that they are valueless, yet it is difficult to bring home any charge of negligence.

Exclusion of Water by Casing.—Where the wells are of a moderate diameter, and welded screwed casing is employed for lining, water can generally be totally excluded from oil wells by pressing the tubes into an impervious stratum above the oil bed. In unexplored territory, where little or nothing is known of the character of the beds, or of the depth at which oil sands will be struck, it is good policy to proceed as far ahead of the casing as possible with a reduced size of drill if water has been passed, so that if an oil source is discovered the casing can be driven or "set" in the most suitable stratum above the oil bed. Should no impervious bed exist near the oil-bearing stratum, one of the methods described hereafter must be employed for excluding the water, but by forcing the casing shoe firmly into a clay or shale a water-tight joint can usually be effected when the casing is good. The exclusion of water in this way often leads to a flow between the casings, and it is no uncommon sight in some oil-fields to observe oil flowing from the inner casing and water flowing from the annular space between the casings.

Exclusion of water is rendered more perfect by the use of the

longer shoes now so commonly preferred by operators in deep and caving territory, and the officials of the American Bureau of Mines have suggested the employment of a series of collars on the bottom length of casing, thus producing the equivalent of a long shoe and increasing frictional resistance.

A process which has been successfully applied in some oil-fields consists in forcing well-puddled clay behind the casings from below. On the point being reached at which it is desired to exclude water, and a suitable seating being established, the column of casing is raised some 10-20 ft., and balls of puddled clay are thrown into the well. A carefully constructed plug packer is then lowered on rods, and on being drawn back after passage through the shoe a secure fit is ensured. The whole column of casing is then raised and lowered a few times in succession to flatten out the clay, then pressed by screws to its seating, forcing the clay firmly up behind the casing. The plug is subsequently drilled up.

Packers.—Water sources can often be effectively isolated by the use of packers, more especially where good screwed casing is used. In the early days packers were made by binding to the casing at the desired spot bags of meal or other cereals, and then lowering the column into the well. When the meal bags were sunk to a position below the water strata where fairly compact beds occurred, the contents gradually swelled by absorption of water, and formed a water-tight joint between the sides of the casing and the well. A somewhat similar use of hemp is sometimes made by binding strands around the casing at a point where the upper loose ends will just pass beneath the shoe of the preceding column when it is lowered. On drawing the column upwards after lowering beneath the shoe of preceding column, the ends of the strands are bent back and push the whole hemp into a bulky mass which presses against the sides of the well as the casing is raised. Both these processes are merely temporary expedients, and it is usual to use specially designed packers which ensure absolute and permanent exclusion of water if properly inserted in suitable strata.

Many packers depend upon the resiliency of rubber to produce a water-tight connection, the expansion of a rubber cylinder being usually performed by direct pressure, or by a tapered cone. One form of packer can be lowered on the pump tubes. The rubber is

constitute such good conductors for electricity that the task appeared hopeless.

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Exclusion of water is rendered more perfect by the use of the

(Fig. 103, A). It is possible to unscrew and remove the casing above the packer if considered expedient, and it is desired to leave packers so set when the well is put to pumping (see Fig. 103, A).

Seals of lead or wood are sometimes used for excluding water by firmly driving a tapered ring of lead or wood into the annular space between the columns of casing at the point where the inner has been cut out and removed. Imperfectly excluded sources of water may thus be prevented from entering the well at these points of weakness.

Cementing Processes of Excluding Water.—In some oil-fields where there is a noticeable absence of compact strata, or where riveted casing has to be employed on account of the large dimensions of the wells, water is often shut off by a process of cementation. In an ordinary well, especially those of large initial diameter, casing is usually economised by cutting and abstracting successive columns of casing from a point some 50-100 ft. above the shoe of the preceding larger column. This operation leaves an annular space increasing in size as the surface is approached. If this space is filled up with cement, not only is the well vastly strengthened, but water is prevented from passing down behind the casings as well as through faulty rivet holes and defective seams in the casing itself. Such a cementation is a long and costly operation, only justified by extreme necessity, as the inner casing has to be filled with earthy matter before the cementation commences to prevent a collapse of the casing and the entrance of cement into the well, and a long interval must elapse before the inserted material can be cleared out, whilst the cement is setting in the annular space. It is advisable that each shoe should be carried into solid ground, otherwise large quantities of cement are often absorbed by loose, partially exhausted oil sands, and even carried underground and bailed from oil wells in the vicinity under some circumstances.

Before commencing a cementation all oil should be removed by bailing, and the space between the casings washed by pumping water down, as a proportion of oil adversely affects the setting of the cement. When there is a high column of liquid in the well the filling can only be performed slowly, or air locks will be formed where cement would subsequently enter and cause trouble

to drill through on cleaning the plug. The material for a plug must be carefully chosen, or it may prove as difficult to remove as drilling a new hole. Some sands are suitable, but others set very solidly, and it is preferable to mix as much clay as possible with the sand to facilitate its abstraction later.

A fluid cement with admixture of clean sharp sand, of the consistency of cream, is stirred up in wooden or iron tubs at the surface, and this is poured through tubes which extend in diminishing size to the lowest point. The upper portion may be 2 in., followed in succession by portions of $1\frac{1}{2}$, 1, and $\frac{3}{4}$ in., whilst a large funnel directs the flow into the tubing at the surface. The descent of a thoroughly mixed solution is thus assured to near its resting place, and no great separation of sand and cement can take place if the tubes are only raised gradually as the cement is inserted. To ensure the proper settlement of the cement the process is conducted in stages, so that the complete operation to the surface occupies several days. It is an advantage to use an almost unadulterated cement at first and gradually add increasing quantities of clean, sharp sand as the surface is approached.

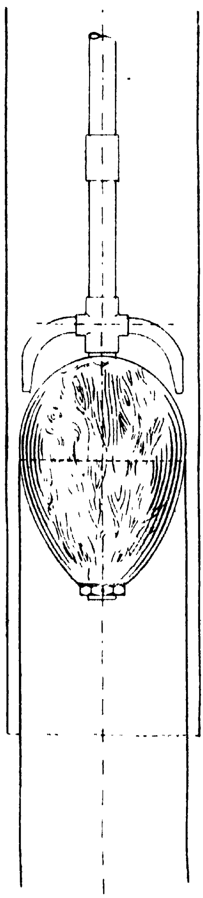


Fig. 104.—Cementing Plug.

Sometimes each column of casing is separately cemented as the well proceeds, in which case it is customary to under-ream below each shoe for several feet, and when the succeeding column has reached its final position and has been cut out, to lower the apparatus shown in Fig. 104 on 2-in. tubes, and fill the annular space with cement.

It will be understood that when such a complete cementation fails in its object, little can be done to remedy any defective setting

or other cause of failure. In such extreme cases the lower part of the well is sometimes filled with cement and left to set, with the uncertain prospect that sufficient cement may enter the ground near the shoe and collect behind the casing to form a solid block. Sometimes the lower part of the casing is perforated with a punch or perforator before the cement is inserted, thus opening other channels for the cement to pass around the casing.

Hermetic columns of casing are frequently cemented in position by the following process, first adopted in California: When a point has been reached where the water should be excluded a head-piece is prepared to screw into the collar of the top length of casing. A central gland and stuffing box to take 2 or 2½ in. tubing allows the cementing tubes to be lowered into the well. Ordinary well tubing is then lowered to the shoe of the casing, and the gland at the surface is well packed, but previous to its insertion an internal projecting nipple has been inserted or attached to the base of the tubing, forming an outlet of reduced area. At the surface of the well, pipe connections to the pump and cement tubs are so arranged that either water or prepared cement fluid may be pumped into the well at will, the change from one to the other being effected by valves or cocks (see Fig. 105).

The column of casing with the tubing is then elevated a few feet, and water is first pumped into the well until a circulation is established behind the casings, and either flows to the surface behind the casing or escapes freely into the earth. The cocks are then manipulated so that a well-mixed cement fluid of the consistency of cream is pumped into the well, the fluid naturally following the direction of the flow behind the casing, and being prevented from rising in the column of casing by the water pressure. After insertion of the predetermined quantity of cement the cocks are arranged to divert clean water into the tubing after a plug of wood has been inserted through the surface T-piece. The latter follows the water down the tubing, and on reaching the base is arrested by the nipple, thus checking the flow of water and indicating to the attendants, by the rise of pressure at the pump, the total expulsion of cement fluid from the tubing. The casing is then lowered on to its seating, and some days are allowed to elapse before the tubing is removed and the water level reduced.

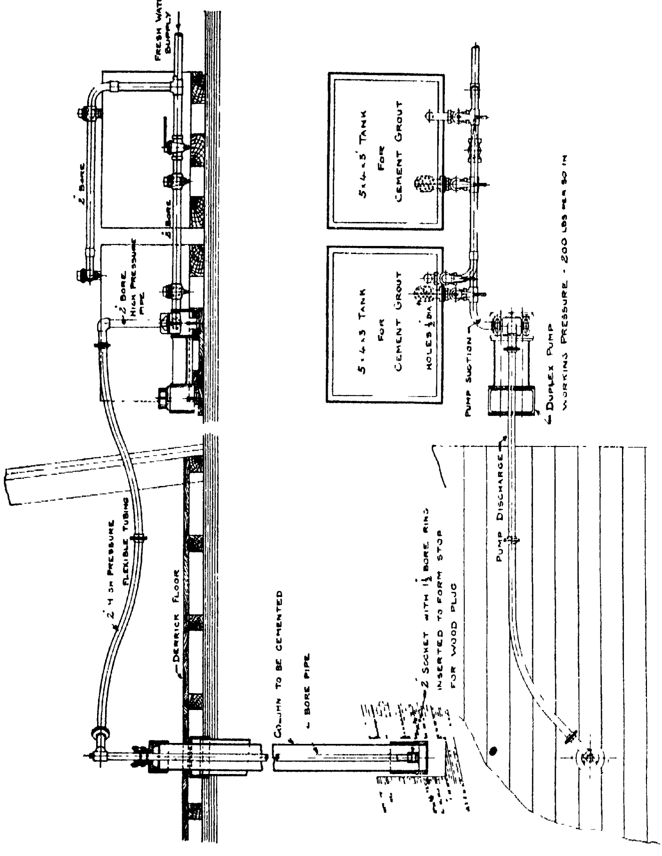
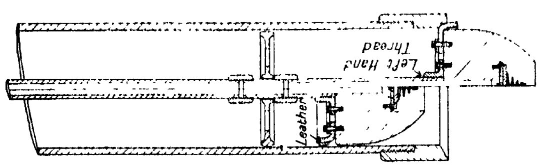


Fig. 105.—General Arrangement for Cementing Well.



Cementing Plug for pumping cement behind casing or forcing up clay previously inserted. In latter case retaining valve is unnecessary.

When defective or damaged casing, or other causes, prevents the adoption of the above system the following arrangement may be applied: A cylindrical wooden or cast-iron frame is prepared to suit the casing in which it is to be inserted. Beneath the centre of the foot plate is attached a non-return valve, above which is a left-hand threaded portion into which 2 or 3 in. cement tubes can be screwed. Around the bottom outer edge of the base plate is attached a cup leather, designed either to distend after emergence from the shoe, or to form a joint on an upward movement of the apparatus, or to expand against the side of the casing on the application of pressure. After washing with water and pumping in cement as before, the tubing is unscrewed and removed, and the apparatus subsequently drilled up. The back-pressure valve in the interval prevents the admission of cement to the well from below, but if defective sections of the casing endanger its admission to the well clay may be deposited on the surface of the apparatus to beyond the faulty place.

Hydraulic systems of drilling in caving formations call for some modification of the usual methods of cementation when water sources demand exclusion. Several methods have been lucidly explained by I. N. Knapp.[1] Having inserted casing and restarted circulation provision is made for the introduction of a cement puddle instead of mud at the desired moment. Prior to the change a wooden plug several feet long is inserted, whose lower portion approximates in diameter the internal diameter of the casing, and whose upper part is a few inches less. The descent of this is effected by pumping in cement mixture until the requisite volume has been inserted, when a second circular wooden plug is inserted, upon the upper surface of which a piece of sacking or belting is nailed to give a tight fit. On switching the pump again to mud the cement column between the two plugs is carried downwards until, when the lower plug has emerged sufficiently from the casing, the cement fluid is forced up behind the casing. The total expulsion of the cement is indicated to the attendants by the sudden rise of pressure in the pumps when the second plug comes

[1] "Cementing Oil and Gas Wells," I. N. Knapp, *Petroleum Review*, 19th September 1914.

into contact with the upper surface of the lower plug. After a period allowed for setting the plugs may be cut up (see Fig. 106).

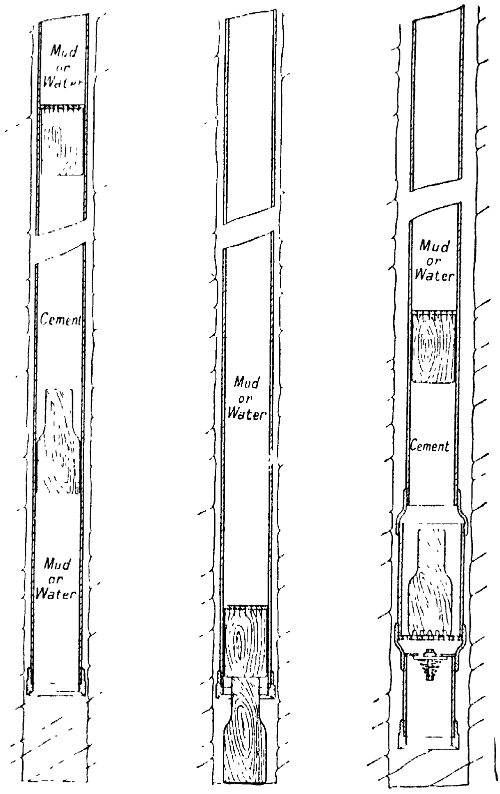


Fig. 106.—Methods of Cementing Flush Drilling Wells.

1. Showing mud being driven ahead of cement mixture followed by water column.
2. Total expulsion of cement mixture behind casing prior to descent of casing to retain the cement.
3. Method of simultaneously washing down and cementing in a column of casing.

A column of casing may require to be flushed into position and cemented in place, when the device shown in Fig. 106 (3) can be used. A back-pressure valve prevents the return of liquid to the casing,

and a grid or projection serves to arrest any descending object immediately above where a swelled nipple gives increased diameter. After flushing the column down with mud in the usual way to the necessary depth, the lower plug, illustrated, is inserted, forced down with cement fluid, upon the surface of which latter is a second plug propelled by mud solution. When the first plug reaches the swelled portion above the valve the cement puddle circulates round its outer edge and around the casing, the process only being checked when the second plug comes into contact with the upper surface of the first.

Reference should not be omitted to the protection against corrosion afforded to casing by cement. In some oil-fields the associated waters are exceedingly corrosive, and attack casing to an alarming degree, against which injury oil provides little protection. Wells from which all upper water has been perfectly excluded develop increasing quantities of water, until a test by packers or otherwise indicates the cause and renders expensive repairs necessary. The provision of a backing of cement or good clay prevents injurious waters from coming into contact with the metal, thus greatly extending the life of casing and constituting a powerful support against internal corrosion that may develop.

CHAPTER X.

THE EXTRACTION OF PETROLEUM AND NATURAL GAS.

Extraction of Petroleum from Pits—Control and Protection of Flowing Wells—Methods of Inducing Artificial Flow of Oil Wells—Pumping—Bailing—Swabbing Process of Oil Extraction—Air-Lift Process of Raising Petroleum—Compressed Air Systems of Raising Oil—Causes and Prevention of Premature Decline of Production in Oil Wells—Emulsions and their Treatment.

Extraction of Petroleum from Pits.—Hundreds of years before the knowledge that petroleum in large quantities could be obtained by drilling wells, oil was raised from shallow pits sunk amidst seepages and along outcrops of oil-bearing strata. The petroleum which by degrees oozed from the containing bed and accumulated in the pits was either skimmed from the surface of water upon which it collected, or was raised in some description of vessel by means of a windlass. This rough method is still practised by peasants and natives in many parts of the world, but particularly in Roumania, where the hand-dug pits had for years been a source of considerable revenue to producers, and had in some districts been the main, if not the sole, source of supply.

Hand-dug pits are often sunk to a depth of 600 ft. in Roumania, and yield as much as 10 tons of oil daily, its extraction being accomplished by the aid of a mule or pony harnessed to a pole fixed to a wooden drum about 4 ft. in diameter around which is coiled the winding rope. The barrel is permitted to descend rapidly by gravity when the drum is disconnected from the shaft, and as soon as the attendant has ascertained that the barrel is filled, the drum is attached by a pin to the shaft and

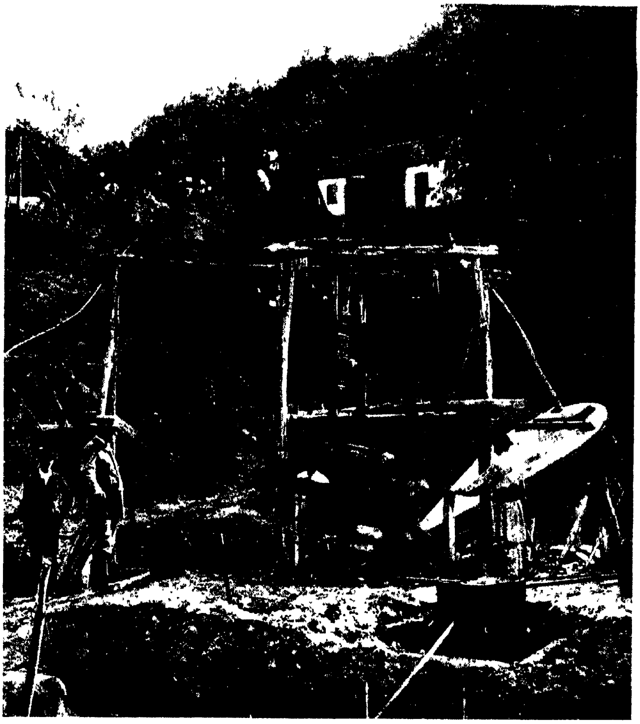
the horse driven round ; the horses are generally blindfolded to prevent them becoming giddy.

Often bullock skins are used for the extraction of oil from pits, in the same way that water is drawn from wells to-day in the East.

In parts of the Caucasus supplies of petroleum are obtained for local consumption from pits. A bucket is used attached to a rope wound round a horizontally mounted spindle, from which there extend four projections at right angles. Both feet and arms are used by the peasant for exerting pressure on the projecting arms when raising a filled vessel. Another common method of raising oil from shallow pits is by means of a long pole pivoted at its centre on top of a vertical support. One end of the pole is vertically above the mouth of the pit when horizontal, and from that end the bucket or vessel for containing the oil is slung by a rope. On the opposite end of the pole is a weight to nearly balance the bucket, and a cord which the operator pulls down when the bucket has filled, and so raises the oil to the surface.

Control and Protection of Flowing Wells.—Too high a value is now placed on petroleum to admit of a repetition of the losses sustained by uncontrolled gushers when the industry was in its infancy. On approaching sources that are likely to give violent eruptions, means are provided to check, or deflect the flow of oil into directions of safety. Massive steel gate valves are held in readiness, and arrangements are made for firmly anchoring the casing to the earth to prevent the upper lengths being blown away. When enormous quantities of sand are ejected with the oil under great pressure, and large and consequently relatively weak casing is often used in lining the well to facilitate the operation of bailing, the control of gushers is often no easy matter.

Operators in the Russian and Roumanian oil-fields were formerly content to rely upon the resistance of chilled cast-iron or steel shields, mounted on timbers some 20 ft. up the derrick, that were drawn over the mouth of the well during eruptions. Heavy cross timbers, to which the 12-in. thick shields were



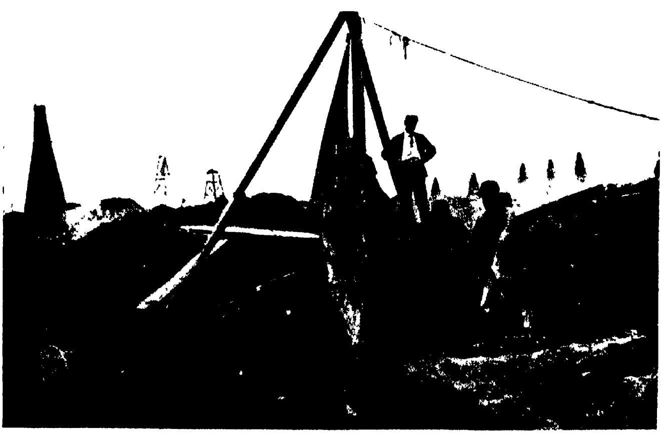


FIG. 107.—SINKING OIL SHAFTS BY HAND.

Sinking Shafts by Hand in Bushtenari Oil-Field of Roumania.
Sinking Pits by Hand in the Binagadi Oil-Field of Russia.

bolted on the underside, were placed in the derrick when a flow was anticipated. The timbers were so pivoted that, although on one side during drilling, they could be drawn over the mouth of the well by ropes from a distance when a flow commenced or appeared imminent.

So destructive is a fiercely discharged mixture of sand, stones, oil, and gas, and often water, that the derricks are sometimes totally demolished, and the chilled cast-iron blocks have been perforated one after another by a particularly violent spouter. Unchecked, the column of oil will rise to an altitude of from 100-300 ft., dismantling, if not destroying, the surface crown fittings, and deluging the neighbourhood in oil. When taken unawares a wooden side structure was often built to the derrick, and the fountain shields were raised, mounted, and pushed over the mouth of the well from one side. This somewhat crude procedure was dictated by several circumstances quite apart from the sand-blast action referred to, and the weakness of large diameter casing, for it has often occurred that the total checking of a flow led to the exclusion and loss of oil. Operators in many oil-fields have observed that the capping of a flowing well often leads to the deflection of the oil, and its re-entry cannot always be induced by clearing and bailing. It is generally thought that indirect channels of admission become clogged through collapses of impervious overlying strata, the reduced gas pressure being insufficient to cause the removal of the obstruction (see pp. 138, 140). Such eventualities are generally avoided by only partially suppressing the flow, an impossible procedure, however, when much sand accompanies the oil, owing to the rapid destruction of valves and fittings.

Unexpected discharges of great violence often cause the total destruction of the derrick in the first few moments, and subsequent operations undertaken for the control of the ejected oil are complicated by the issue of oil around the well, and even from fissures in the earth for some radius round the well. Such problems have been attacked in Russia, Roumania, and Mexico by building steel or concrete structures

over the well, through which vertical and side orifices are left for the removal of the products. These latter may be gradually closed by valves and strengthened at convenience.

A method which has been successfully repeated in several cases where enormous volumes of gas at high pressure have impeded surface operations, is to tunnel to the well, and cut an orifice in the casings, through which the oil can be led by a suitably attached pipe to a safe distance from the field. The great Columbia well of Moreni, Roumania, was, in 1913, treated in this way, and during the whole period of its flow the product was safely led to reservoirs removed from the danger zone.

Ordinary gas and oil wells are controlled by massive steel gate valves, which are generally fixed in position before a flow commences. The discharge is often led to a distance under its natural pressure when unaccompanied by sand. Gas flows are always continuous, and its expansion under diminished pressure on its exit from the well sometimes reduces the temperature sufficiently to create condensation of moisture, and cause ice to accumulate around the mouth of the well, and even in the pipes, if moisture is present with the gas. Gas jets are, in such cases, kept burning to raise the temperature.

Closed gas pressures in parts of Pennsylvania, West Virginia, Canada, Surakhany, Russia, Oklahoma, Kansas, and the Gulf regions of America, may reach several hundred pounds per square inch, but open pressures are much less, and only rarely exceed 10-20 lbs. per square inch. Enormous open pressures are sometimes recorded in the early development of oil and gas fields (see Fig. 13), when the roar may be heard for miles, and close approach to the well is attended by considerable discomfort unless the ears are protected. In the presence of sand, lining tubes are torn to shreds, and fine sand is strewn for miles over the surrounding country.

Natural earth pressures rarely exceed that due to hydrostatic head, consequently undesirable flows of gas and oil can be suppressed, and their effect neutralised by the maintenance of a counterbalancing column of liquid in the bore hole. Unless maintained at its full head by pressure, the column becomes

lightened by gas, and consequently flows, with the result that wells run wild, and get out of hand in a few moments. Heavy mud mixtures are an additional safeguard against "*blow-outs*," but with the addition of suitable surface connections it has been shown by the American Bureau of Mines that all likely pressures can be satisfactorily dealt with. These measures are explained and illustrated on p. 392, and are particularly useful for keeping a wild well quiet whilst preparations for its effective control are undertaken. Experiments have shown that the re-entry of oil and gas can be induced at convenience by reducing the level of liquid by bailing or other means.

The enormous volumes of inflammable gas liberated by a flowing well are a menace to a wide area, consequently increasing use is being made of fans to exhaust the gas and convey it to a distance, even if it is eventually wasted.

Oil frequently commences to flow either incessantly or intermittently when a prolific source is being approached or is entered during drilling. When inconvenient to leave the rig in position for later completion of the well a surface attachment is fitted to the casing, known as a casing head, furnished with lateral outlets, through which oil can be led away to tanks. Cable drilling may be continued through a flowing source by means of an "*oil saver*," shown in Fig. 108. An externally turned and polished tube is attached to the cable when the tools have been lowered to the working point, and this passes through the gland and stuffing box of a special casing head cap securely fixed in position by set-screws. On withdrawing the cable and substituting a bailer for cleaning operations a cap is threaded on to the sand line, and held in position exactly as the oil saver. A little oil escapes around the sand line during a flow, and the cap has to be removed or inserted each time the bailer is raised or lowered.

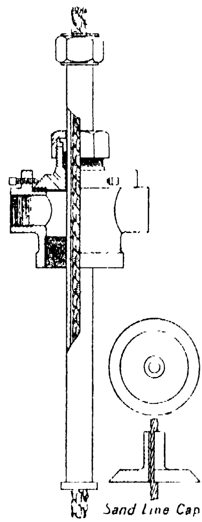


Fig. 108.--Casing Head and Oil Saver.

Flowing wells sometimes ignite through accident or negligence, and large or violent gushers may prove exceedingly difficult to extinguish. Burning wells of moderate proportions may be overpowered by suddenly impinging upon the flame near the mouth of the well some non-combustible gas that momentarily prevents access of air to support combustion. Steam is an effective agent, usually procurable at no great expense, and it can be suddenly directed in large volumes under a high pressure from a series of jets arranged around the burning well. In some cases steam from as many as forty boilers has been suddenly projected on to a burning well. Carbon dioxide is a more active agent if available.

Burning wells that cannot be closely approached for surface operations on account of the great heat, and on which steam and chemicals have failed, may be attacked by tunnelling, and either tapping the well in the way already described, or squeezing the casing flat with hydraulic or screw jacks and so reducing the flow.

Methods of Inducing Artificial Flow of Oil Wells.—After a well has flowed naturally for a while, the discharges become less and less frequent until they cease altogether, but often long before the period of total inactivity is reached, in wells where little sand accompanies the oil, a column of 2-3 in. tubing is lowered into the well, and the space between the tubing and well casing sealed, so that the diminishing quantities of gas are thereby forced to escape through the reduced sized piping. If there is still a fair evolution of gas, the oil may continue to flow unaided for a further time, until the reduced output makes it necessary to use mechanical means of raising the oil. Sometimes a packer is attached to the tubing near the bottom of the well, the gas being thereby compelled to find a direct outlet through the small tubes without collecting under pressure in the well above the oil. Packers are described under water exclusion, p. 444.

Most oil wells can be induced to flow, where there is a high level of liquid or a fair quantity of gas, by closing the outlet of gas for a while, when the liquid becomes supercharged with gas and will be ejected when relief is afforded.

Sometimes the intervals between successive flows can be reduced by intermittently admitting a small quantity of compressed air to

the bottom of the well through small tubes, the aeration being sufficient to cause the oil to flow. The most efficient period between successive admissions of air must be ascertained by direct experiment in each separate case. Flows may be renewed in some cases by swabbing with a plunger fitted with upward opening internal valve, lowered on a rope and withdrawn rapidly (see p. 484). Bailing likewise will often induce periodical flows long after a well has ceased to erupt unaided.

Pumping.—The method of extracting petroleum from an oil well is decided by circumstances, which are to some extent dependent upon the following conditions:—

1. Amount of gas evolved.
2. Depth of well and sometimes diameter.
3. Level of liquid.
4. Amount of sand suspended in the oil.
5. Productivity of petroleum sources.

By far the most general and the cheapest method of extracting petroleum from oil wells is by pumping, but this is not always possible, on account of the large quantities of sand accompanying the oil.

The common oil-well pump is a cylindrical steel or cast-iron chamber usually from 4-7 ft. long, screwed at the upper and lower ends for the attachment of the rising main and suction valve respectively, and in which works a plunger or bucket, fitted with an internal valve. The hollow plunger is either externally recessed for a wrapping of hemp, or made to take several cup leathers, whilst the interior has a machined seat at the top on which a ball valve between guides finds a seating. The lower or suction valve consists of a fitting with a gun-metal or steel ball valve and seating, the body of which is suitably packed with hemp or leather rings to tightly fit the pump barrel, and rest upon a shoulder or cone on the suction attachment. The pump barrel is lowered on 2-3 in. tubing to the bottom of the well, the pump plunger being lowered into the barrel by "sucker" or pump rods. The lower end of the plunger is often screwed to correspond with a similarly screwed portion of the suction or lower valve, so that by lowering the plunger carefully upon the suction valve and rotating the sucker

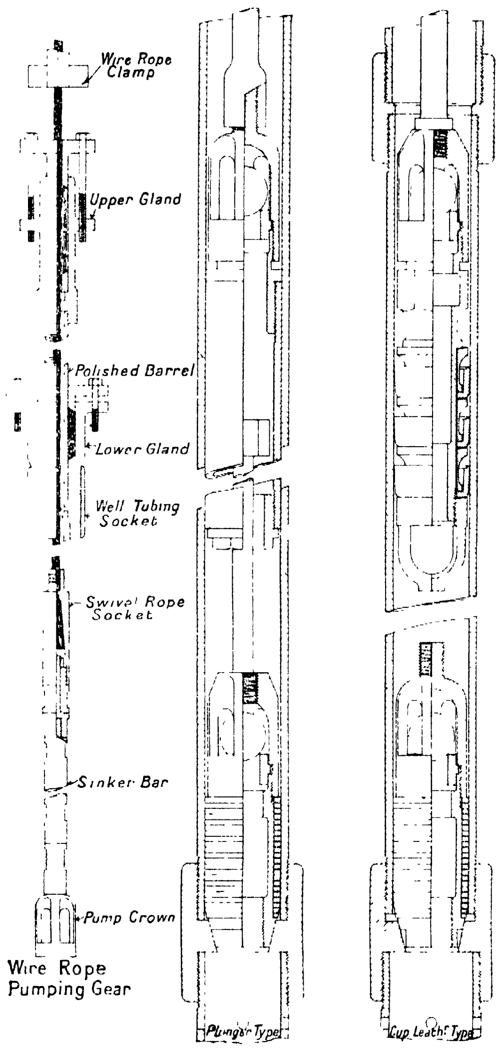
rods a few times, the lower valve can be attached to the plunger and withdrawn from the well with the plunger for examination without removing the tubing to which the pump barrel is connected.

Numerous varieties of pumps are now advertised by the oil-well supply houses, but the simple cast-iron or steel barrel with leather cups on the working plunger finds most acceptance for ordinary duties when there are no complications from excessive gas, high viscosity of oil, or much sand. Dense oils of the usual Californian grade, where sand generally accompanies the oil, can best be raised by plunger pumps, in which the friction of a film of oil between a long hollow plunger and the barrel is sufficient to prevent any appreciable slip. Barrels become scored by sand in course of time, but they resist the action longer than other forms of plungers, and the author has examined plungers that have been in constant use for six months without renewal.

Rarely is oil quite free from fine sand, silt, or argillaceous matter, that in course of time wears away cup leathers or packing rings whatever be their construction or make, and the problem really resolves itself into deciding whether the barrel shall outlast the plunger or vice versa. The former is naturally preferred, as the renewal of plunger packing is the simpler and cheaper operation. Some plungers are furnished with means of taking up wear by compressing the packing without removing the plunger; in others a constant pressure is exerted on the packing by a spiral spring in compression acting against a loose collar. Rubber, hemp, and other materials are used as packing, whilst cups are either best butt leather or some special mixture that can be pressed into shape and will retain its form.

Some plunger types of well pump are designed so that the lower valve and plunger are attached, and can be inserted and removed together. This connection is secured by attachment to the lower valve of a rod over which the plunger slides when the pump is put in motion after being lowered upon its seating.

One of the difficulties of pumping arises from the effect of gas which, at times, forms pockets in the barrels, and prevents the actuation of the valves. Special pumps are designed to overcome or minimise this feature with varying success. A



A B C

FIG. 109.—DEEP WELL PUMPS.

A. Arrangement for Wire Line Pumping.

B. Plunger Pump, with means for withdrawal of Suction Valve

C. Common Cup-Leather Type of Pump.

simple and effective way of counteracting the influence of gas is to insert the pump inside an outer and somewhat larger tube perforated at its upper extremity. Admission to the pump suction is only possible *via* the top perforation of the outer tube, during which movement gas separates from the oils and rises, whilst oil, largely freed of gas, descends to the pump intake.

Mechanically operated valves are the feature of one pump designed to reduce gas trouble, but undesirable complications are necessarily introduced.

Many little refinements are incorporated in various classes of pumps to meet imaginary or real troubles. A feature of value is the removable ball seatings supplied with some valves.

Pumping by wire line in place of sucker rods is now a recognised practice. At the surface is a special wire rope clamp to securely couple the line to the reciprocating part of the head gear; and to avoid the wear and tear that would arise from the movement of a wire line in a stuffing box, an "oil saver" device is used. A convenient form of gland and stuffing box is attached to the casing head, and through this passes the polished oil-saver tube that encircles the wire rope. The gravity return of the working valves and plunger is ensured by the attachment of a sinker bar or a few steel sucker rods to the valve spindle. Spinning of the rope is taken up by a swivel between the sinker and the rope socket to which the rope is united.

Fig. 109 illustrates three types of pumps where all the essential details are shown. Simplicity should always be given preference, and only those of the best quality and workmanship should be ordered.

Pump Tubes.—The pump tubing on which the pumps are lowered is specially made for the purpose, ordinary piping not being satisfactory. It is usually slightly heavier than standard piping, the sockets are longer, and the screwing must be absolutely true to ensure a straight joint and quite air-tight column when coupled up. The joints must very nearly butt, and the inside

edges must be slightly chamfered to remove any burrs which would damage the packing or cup leathers during insertion. The tubing must also be quite round and free from rough edges or seams internally, and all should be tested prior to use by the insertion of a plug slightly less in diameter than the tubing.

American standard well tubing has the following specification:—

Size.	Diameter in Inches. External.	Diameter in Inches. Internal.	Thickness.	Weight per Foot with Couplings.	Threads per Inch.	Couplings. Diameter	Couplings. Length.	Couplings. Weight in Lbs.
In.							In.	
$1\frac{1}{2}$	1.900	1.610	.145	2.748	$11\frac{1}{2}$	2.29	$2\frac{7}{8}$	1.103
2	2.375	1.995	.190	4.500	$11\frac{1}{2}$	2.84	$3\frac{5}{8}$	2.146
$2\frac{1}{2}$	2.895	2.441	.217	6.250	$11\frac{1}{2}$	3.45	$4\frac{1}{8}$	3.636
3	3.500	3.018	.241	8.500	$11\frac{1}{2}$	4.072	$4\frac{1}{8}$	4.366
4	4.500	3.990	.255	11.750	8	5.233	$4\frac{1}{8}$	6.673

Sucker Pump Rods.—Sucker or pump rods partake of several forms, their choice being largely dictated by cost in the locality n which they are used; $\frac{1}{2}$-$\frac{3}{4}$ in. diameter tubing is often used, but where the wells are deep specially long sockets should be attached. A popular practice at one time was to employ round or octagonal wooden (ash) poles with screwed straps riveted to the ends as in ash drilling poles, and their lightness and reduced weight when submerged in liquid were certainly contributory advantages.

Under usual circumstances the use of solid iron and steel sucker rods is favoured, especially when the size of pump tubing does not exceed $2\frac{1}{2}$ in. diameter. The solid rods are from $\frac{9}{16}$-$\frac{7}{8}$ in. in diameter, and have screwed ends and collars for their attachment, and shoulders for suspension from wrenches or elevators. Spare screwed ends should be kept in stock for welding to the rods if an end becomes damaged.

For lowering tube sucker rods a small hinged clamp with suspension slings is used, and the joints are screwed up with pipe wrenches, but with wooden or iron sucker rods a convenient elevator, shown in Fig. 110, is used. When held horizontally the wrench part passes freely below the collar on the rod, but

on attaining a vertical position the extending limb prevents the rod from slipping out.

When an oil well has been completed and set to pumping, it is usual to leave the derrick and bull wheel for withdrawing the sucker rods when the pump leathers or packing need renewing. With wells of 1,000-2,000 ft. in depth some six men are needed to manipulate the rods, and they raise the rods by turning the bull wheel, to which a light wire line has been attached after passage over a small pulley in the summit of the derrick. Where no derrick is left, and in some cases where the derricks do remain, the rods are lifted by horse power in conjunction with a portable form of shear legs which can speedily be erected and conveyed about the field.

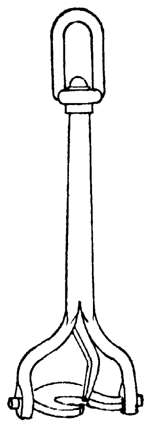


Fig. 110. Sucker Rod Elevator.

Pulling machines are now largely used in some oil-fields where circumstances do not justify the retention of a derrick and other appliances at the surface. Such machines are portable, and are generally operated by horses that are used for transportation. They are composed of a mast that can be raised to a vertical position and held by guy ropes, and a light winch mounted in a basal framework. Power-driven self-contained pulling machines are also in use, in some cases combining also provision for pumping.

The use of steel wire rope for operating well pumps has already been referred to, but it is advisable to call attention to the advisability of inserting a temper screw somewhere to take up the stretch of the rope during work.

Surface Fixtures for Pumping.—When trial pumping an oil well the walking beam of the drilling rig is generally used for transmitting the motion to the pump rods. A "*casing head*" is attached to the top length of casing, and from the side outlets are led two pipes to conduct the gas, and, if the well flows, the oil also to the desired location. The gas can be led away direct to the boilers to be burnt as fuel, or may be conducted to reservoirs from which gas engines derive their power.

The rising main tubes are continued to a height of about 2 ft. above the derrick floor, where a tee is introduced into which the oil

outlet pipe is led which connects with the storage. Above the tee is attached a brass stuffing box in which works a polished steel rod screwed to the sucker rods, and which can be connected to the walking beam at any desired position by a "*grip adjuster*." This method is sometimes retained for permanent pumping, but more often the walking beam is replaced by some smaller and more convenient form of motion transmitter, especially as wells are generally pumped in groups by means of "*jerker lines*" which transmit a horizontal motion.

Where wells are widely separated, or individual or isolated wells have to be pumped, the walking beam system is to be recommended, as the crankshaft takes its drive direct from an electric motor, gas, oil, or steam engine, or other motive power which may be employed. In the hilly districts of West Virginia electricity is largely used in this way by the South Pennsylvanian Oil Company for pumping widely separated wells, where the production from individual wells often does not exceed half a barrel of oil daily.

The bell crank lever is the almost universal method of pumping when a movement in a horizontal direction has to be transformed into a vertical reciprocating motion. Where timber is inexpensive, and ironwork is dear on account of freight or duty, a wooden crank may be used, but a lighter or more convenient form of pumping "*jack*" is shown in Fig. 111. The timber crank can be made by any carpenter, and can be strengthened by the addition of a few wrought-iron plates. A wrought-iron stirrup connects the "*jerker line*" to the crank, and a simple connecting joint couples the oscillation beam to the crank. A considerable amount of power can be saved by partially balancing the weight of the sucker rods by extending the oscillation beam on the side removed from the well and suspending weights near its extremity.

Metal pumping jacks are made in combined wrought and malleable iron, and sometimes for lightness and simplicity in wrought-iron tubing. The "Simplex" type is quite suitable for wells of medium depth and pumping capacity, and has given satisfaction where installed under the author's direction. The heavy size of pumping jack only weighs about 500 lbs., and costs about \$20, and it has the special advantage over many other types of transmitting a direct pull to the pump rods, and avoiding the

lateral strains which in many designs are thrown on the polished rod and gland.

Self-contained pumping powers for isolated wells are now standardised in the United States of America. They consist of geared frames arranged to transmit an oscillatory movement to pivoted walking beams slung on low standards. Provision is usually made for balancing the weight of the sucker rods, and the base plate is designed for the mounting of a gas or oil engine or an electric motor according to the requirements of the locality for which they are intended. One extensively advertised power is especially well designed to obtain a straight pull on the pump rods.

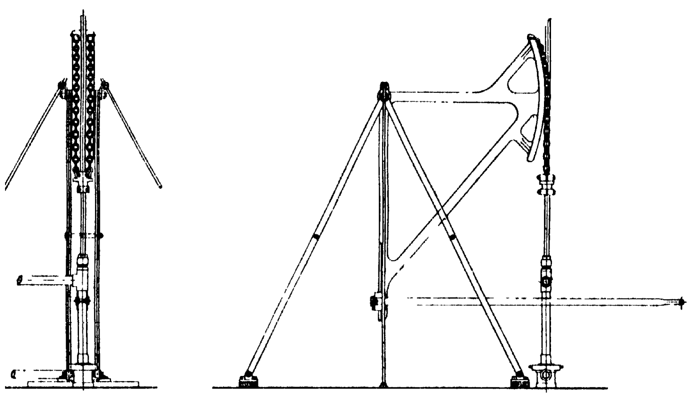


Fig. 111.—Simplex Pumping Jack.

Action of Well Pumps.—Rarely does the flow of oil from a well pump correspond with the stroke of the plunger or bear any ascertainable relationship to the movement of the valves. Oil is usually discharged more or less violently at irregular intervals, commencing with a slow expulsion of foam followed by an increasingly fierce ejection of oil or oil and gas. At other times, without any warning, oil is vigorously expelled in a solid column, followed by a piston of gas that issues with considerable noise and throws a high temporary pressure upon oil tanks if enclosed or gas tanks if employed.

Pumps virtually flow by heads as a flowing well, and the theory of this action rests upon the supersaturation of oil with gas at the

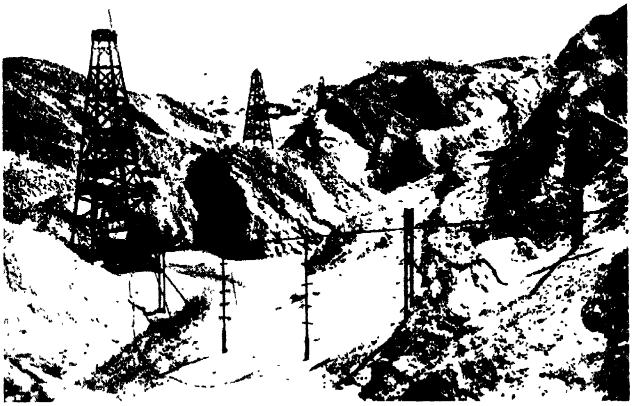
base of the well and the comparative immunity from gas of the undisturbed liquid in the well. Fresh oil takes the path of least resistance, which, in a pumping well, is always in the pump tubing where movements of the pump rods agitate the fluid, assist in liberating dissolved gases, and so lighten the column of liquid till it will flow unaided through the pump till the rate of ejection exceeds the inflow of fresh oil and gas. Flow by head may proceed for a few minutes only or continue for hours, yielding in that period many times the capacity of the pump. It is on account of this feature that 1¾-in. pumps are usually ample to deal with quite large wells in which there is much gas. The actual capacity of a 1¾-in. diameter pump with 4-ft. stroke at 30 per minute and 20 per cent. slip would be about 55 tons (410 barrels) of oil per day of twenty-four hours. Were it not for the flows by head independently of the action of valves, pumps would rarely act in light oil districts owing to the interference of gas with the regular action of the valves.

When there is little gas, well pumps act normally, and give a discharge of oil at each stroke of the plunger; in fact, there is a double flow, the sucker rods displacing oil on their descent and expelling their equivalent volume in oil. Elsewhere are discussed the relative advantages of intermittent and continuous pumping (p. 499) and other features connected with pumping oil wells.

Transmission of Power for Pumping.—Where it is necessary to instal at each well a complete pumping equipment, including motor, the extraction of oil becomes costly; indeed, the profitable exploitation of some oil-fields is entirely due to the cheapness of multiple pumping. The size and strength of a pumping unit is decided by (1) the nature of the ground, (2) the distance of the wells apart, (3) the size of the pumps, (4) whether the wells are pumped continuously or intermittently. If the ground is fairly level and open, and the wells are not further removed than 600-700 ft. from each other, units of forty to fifty can be pumped with economy by "jerker lines," but many oil producers prefer pumping units of twelve to twenty-five wells, on account of the fewer number of wells that become unproductive if a breakdown occurs.

In all cases a central station is needed, where the power is either generated and transmitted to the wells or transformed into

PLATE XXXII.



A

B

FIG. 112. VIEWS IN THE PERUVIAN OIL-FIELDS.

A Showing method of Jerker line transmission over broken country.

B Showing well being pumped by Jerker lines, also the sudden change of barren and hard calcareous sandstone to an oil-saturated sand (on which the horse is standing). When the sand is disturbed the dark discoloration of the sand is visible.

suitable motions. The power itself may be electricity, steam, or internal combustion engines, but in all cases it is transmitted by gearing or belting or chain drive to a frame that actuates the wells through the medium of tension rods. Power is only needed for lifting the bucket when pumping, as the weight of the rods carries the plunger back, consequently all the power applied to the wells is tensional. This fact enables considerable power to be transmitted over long distances if compression forces are entirely avoided, and it further permits the employment of iron rods or even wire ropes. A common American type of pumping "*power*" is shown in Fig. 113, where it will be seen that it consists of a central

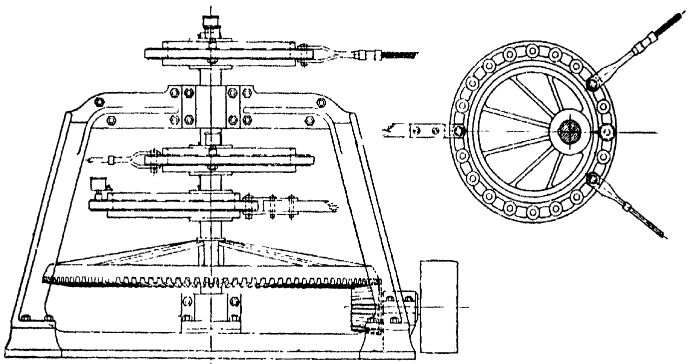


Fig. 113.—Common Type of Pumping Power.
Showing wooden and iron rods, also wire rope jerker lines.

vertical shaft driven by bevel gearing from a horizontal spindle, several eccentrics and straps being attached to the vertical shaft. On the outer flange of the eccentric straps are bored a number of holes for the connection of wrought-iron straps attached to the transmission lines, so that when the shaft revolves the transmission lines are given a slight oscillating motion, as well as a reciprocating, horizontal movement, equal to the throw of the eccentric. From each eccentric are led a number of transmission lines in different directions, so that the power is fairly evenly balanced in practice.

In large pumping stations, where power for from thirty to fifty wells is transmitted, a horizontal shaft fitted with eccentrics is often constructed. A heavy wooden band wheel, securely keyed to the

shaft, takes the drive by the belt, as well as acts as a flywheel in storing up energy to smoothly pass the dead centres. The connecting rods attached to the eccentrics have guides working in bushed bearings where the motion is transformed to a horizontal movement (see Fig. 114).

Considerable care is needed in arranging the work of a large pumping station to deal with forty to fifty wells averaging, say, 1,200-1,500 ft. deep, in order to equally distribute the load.

Jerker or Transmission Lines.—Until a few years ago, transmission or "jerker" lines were generally composed of timber, and even now this practice occasionally prevails. The size of timber used for jerker lines naturally depends upon the power to be transmitted, but they vary from 8 in. by 4 in. on main lines to 3 in. by 2 in. on branch lines. The rods are coupled together by flat sheet-iron straps, through which a few bolts are inserted and tightened up. The jerker lines are suspended by wooden or iron swingers in swing brackets, placed at sufficiently close intervals to prevent any undue sag between the points of suspension. Each swing bracket acts as a lateral guide in addition to a support, so that side wind pressures do not deflect the rods. Friction is reduced to a minimum by the attachment of a strip of wood against which the swinger alone rubs if deflected by wind. Motion is transmitted to any desired direction by occasional bell cranks or change wheels, from which tensional rods are led off in the direction of wells required to be operated.

When iron rods are used as transmission lines, they are provided with a clasping device which allows the rods to be quickly coupled together, and at each joint a projection is provided by which they may be suspended on swingers from suspension brackets. Rope transmission lines are manufactured from thick iron wire, and are coupled together by special fasteners provided for the purpose.

A very simple and effective way of transmitting and deflecting tension rods is to use pulleys mounted horizontally or vertically as required. At each pulley a short length of chain is inserted to accommodate the change of direction, and at each well a wire line can be led over the top derrick pulley and direct on to the pump.

Multiple pumping reduces costs considerably when there are no technical objections to its introduction. Where the oil is of

light density, unaccompanied by much sand that would necessitate frequent pulling and cleaning, and the contours of the ground

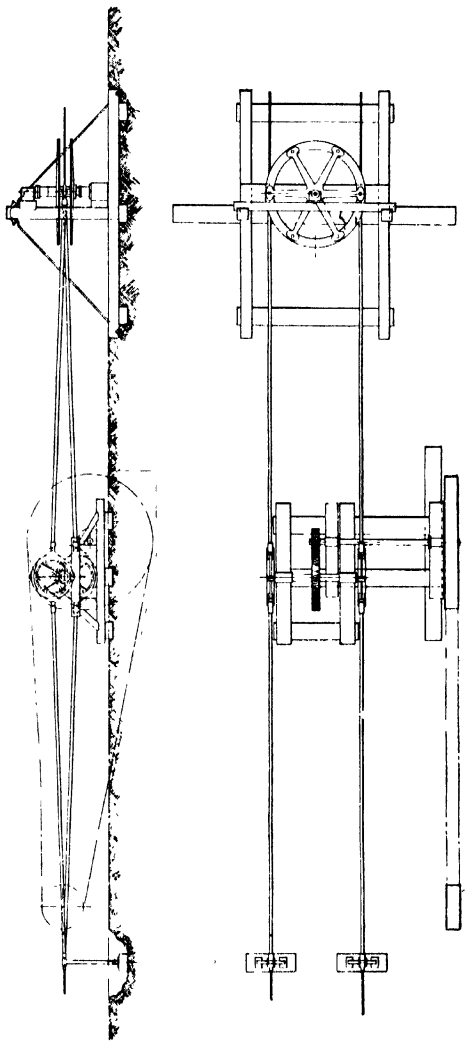


Fig. 114.—Pumping Frame for Operating Large Groups of Wells.

present no obstacles to the deviation of jerker lines, the cost of extraction may be very low, although the mechanical efficiency of

the plant may not be high. Taking a group of 20 wells averaging 1,500 ft. in depth, operated 24 hours daily with 1¾-in. pumps, with a yield per well of 25 barrels of oil and 25 barrels of water, the theoretical power required for the duty, assuming the oil to weigh 8.5 lbs. per gallon, and the water 10 lbs. per gallon, would be :—

$$\frac{20 \times (25 \times 298 + 25 \times 350) \times 1,500}{24 \times 60 \times 33,000} = \frac{20 \times 16,200 \times 1,500}{24 \times 60 \times 33,000} = \frac{1,350}{132} = 10 \text{ H.P.}$$

In practice about 40 H.P. would be required for this work. The efficiency of the pumping service being therefore $\frac{10}{40} \times 100 = 25$ per cent. Fuel consumption with steam power under oil-field conditions would, with 50 lbs. of steam per H.P. hour, and 12 lbs. steam per lb. of oil fuel, be :—

$$\frac{40 \times 50}{12} = 166 \text{ lbs. of oil per hour}$$
$$= 4,000 \text{ ,, ,, day}$$
$$= 13.5 \text{ barrels ,, ,,}$$

One barrel of oil, therefore, raises—

$$\begin{array}{l} \text{Wells. Bls.} \\ \frac{20 \times 50}{13.5} = 74 \text{ barrels of liquid, of which half is oil} \\ \qquad = 37 \text{ ,, oil} \end{array}$$

Fuel consumption is, therefore, about 3 per cent. of the oil raised.

With oil at $1 per barrel the cost of fuel would be about 3 cents per barrel (10½ pence per ton) of production, or 70 cents per well per diem. The labour costs would naturally differ in every oil-field, and vary from 24 cents to 96 cents (1 to 4 shillings) per well per day, or 1 cent to 3.8 cents per barrel. With a gas engine using gas from the wells the cost of power would be negligible. An oil engine under similar conditions would consume about 30 lbs. of oil per hour, say 2.5 barrels daily, or cost only 0.5 cent per barrel of oil raised; between one-fifth and one-sixth that of the fuel consumed by a steam engine under oil-field conditions.

Heavy viscous oils, such as those of most of the Californian oil-fields, accompanied often by from 3-5 per cent. of sand, are generally pumped by 3-in. plunger pumps from the walking beam as separate units. Under these less favourable circumstances the power consumed varies from 4-7 H.P. according to depth, viscosity of oil, and proportion of sand. In the Midway-Sunset

oil-field the total cost of pumping a group of 15 wells 1,000 ft. deep was $7 per well daily, equal to about 12 cents per barrel (3s. 6d. per ton) of oil extracted. In another case, where electrical energy was employed, 91 wells averaging 1,650 ft. deep, and giving an average output of 101.5 barrels daily, consumed on an average 84.8 kw. per well per day, equal to .835 kw. per barrel. At a price of 1.5 cents per kw.-hour for power, the cost per well per diem would be $1.27, or 1.24 cents per barrel[1] (4.3 pence per ton).

Bailing.—In some oil-fields, notably those of Baku and Roumania, so much suspended sand accompanies the oil that all apparatus in which plungers and small valves form a part is useless for raising the oil, and it is usually extracted by bailing. The bailers are long cylindrical vessels made of sheet-iron sleeves riveted or welded together, fitted with a cast-iron lift valve opening inwards at the lower extremity, and a suspension hook at the upper end. An internally screwed wrought-iron ring is attached to the bottom of the bailer, into which is screwed the valve and seating, the valve spindle extending 6-8 in. beneath the guide which directs the valve on to its seating. When the bailer is lowered into the liquid the valve lifts and admits the fluid, which fluid passes freely through the vessel so long as it descends, but immediately the bailer ascends the valve closes and the admitted fluid is raised to the surface. By lowering the filled bailer on to a solid base the extending spindle is forced inwards, the valve opens, and the enclosed liquid flows away. Fig. 115 shows the usual arrangement of a well-designed bailing well.

The ordinary bailers vary in diameter from 6-14 in., and from 10-60 ft. in length, depending upon the diameter of well, depth of liquid, and yield of oil. The riveted type were formerly rendered water-tight by soldering the joints, and were strengthened with a ⅜-in. safety rod attached to a cross bar at the top and bottom of the bailer. Electrical and oxy-acetylene welding has replaced riveting and soldering with great advantage. Sometimes they are now made by welding spirals of sheet iron. The upper and lower sections are tapered somewhat for guiding the bailer into the well, and protecting the valve and suspension hook.

[1] "The Petroleum Industry of California," R. P. M'Laughlin, Bulletin 69, California State Mining Bureau.

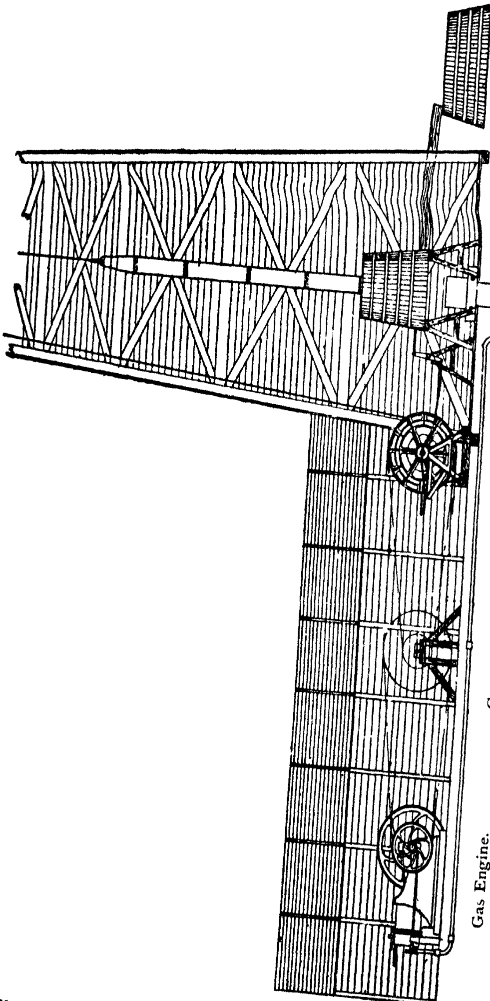


Fig. 115.—General Arrangement of Bailing Oil Well. (Shows also Gas Engine drawing Gas from Well.)

When a new well is being bailed, immense quantities of sand frequently rise in the well, necessitating constant bailing from the bottom of the well to prevent, by its accumulation, the total

exclusion of the oil, and it is not unusual for the above described bailers to raise hundreds of tons of sand daily for months at a time before the inlet of sand diminishes. When unattended with water, oil sands are very fluid, closely resembling fresh caviare in appearance, and they readily enter and fill the bailers, from which they also flow with equal ease on the opening of the valve, but a little water with the sand renders its admission to the bailer more difficult, and likewise its extraction may necessitate the removal of the valve and seating owing to the compact mass which forms.

The great length of bailers in some cases is only to give increased capacity, but it will be at once evident that any slight deflection of the casing would prevent the free descent of such a long vessel little less in diameter than the well. In the Russian and Roumanian oil-fields the wells frequently become deflected from the vertical near their base as a consequence of landslides, and a large capacity is maintained by using jointed bailers, where the bailer is divided into several sections connected by hollow knuckle joints. Such bailers enable wells with a considerable curvature to be bailed at a profit when they would otherwise be abandoned. Some flexible bailers have been made from flexible metallic tubing connected together in lengths to give the desired capacity. Fig. 116 shows types of bailers used for extracting oil.

Bailing is conducted by means of a wire rope and a bailing drum of from 8-16 ft. circumference, to one side of which runs freely on the main shaft a pulley fitted with side friction blocks which fit into a depression on the side of the drum. The main pulley receives its drive direct by belting from the engine, and is drawn by levers towards the drum when it is desired to raise the bailer after its descent by gravity into the well. A powerful foot-brake is provided to regulate the speed of descent and prevent over-winding. The speed of bailing is from 1,000-1,500 ft. a minute, and the power required varies from 30-150 H.P., according to the speed, size of bailer, quantity of water and of sand. Fig. 117 shows the common type of bailing drum used in Russia.

Customarily Roumanian drums which are designed for smaller productions are gear-driven, and the drums do not exceed 2 ft diameter.

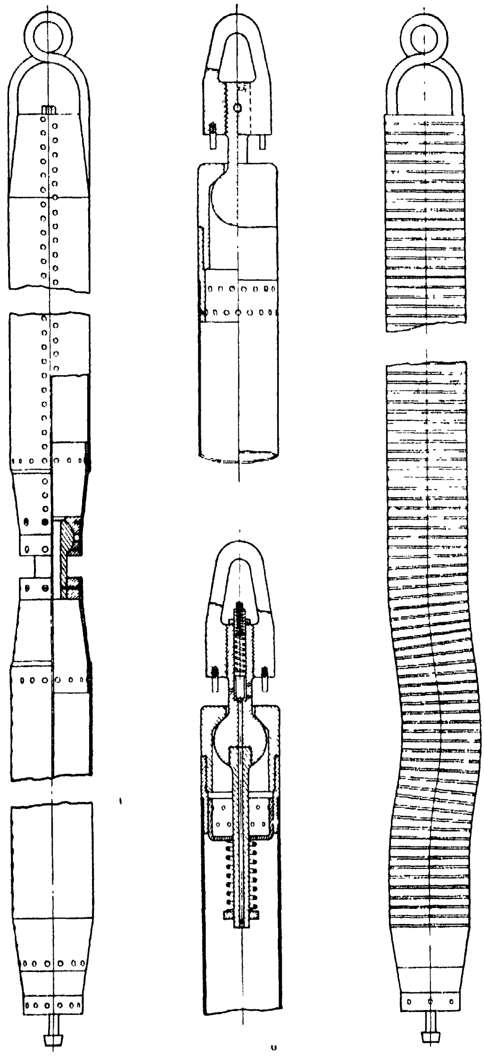


Fig. 116.—Bailers.

1. Jointed Bailer for Curved Wells.
2. Special Bailer Valves for use in Gassy Wells where contents are expelled from bailer during ascent.
3. Flexible Tube Bailer for Curved Wells.

The bailing ropes are from $\frac{5}{8}$-$\frac{3}{4}$ in. in diameter, and they have to be constructed of fine crucible steel wire to withstand the rough treatment to which they are subjected in bailing. Flexibility is discarded in favour of resistance to abrasion, which always takes place through the swaying rope coming into contact with the casing. The rope also suffers severely from excessive and repeated twisting when the high velocity descent

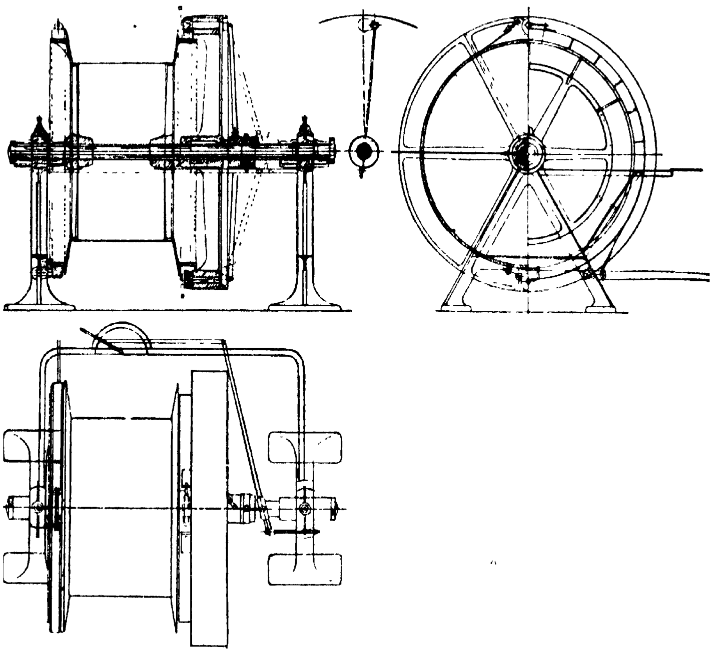


Fig. 117.—Russian Bailing Drum.

of the bailer is suddenly and temporarily checked as it strikes the surface of the liquid, the bailing attendant not being able to apply the brake in time to prevent 30-100 ft. of rope coiling itself up on the top of the bailer before the latter fills and sinks more slowly in the liquid. For bailing wells of 1,500 ft. it is usual to employ a rope of 2,000-2,500 ft. to allow for periodically cutting off pieces of the rope near the bailer as they show signs of dangerous wear.

The oil is emptied into a "bailing tub" before it flows away

to tanks or other receptacles where the sand may settle prior to its removal to the main storage. The bailing tubs are wooden vats about 6 ft. in diameter and 5 ft. high, placed on trestles over the mouth of the well (see Fig. 115). There is a central orifice through which the bailer can pass, and extending to about a foot above the base there is a bored wooden block on the surface of which slides a strip with a sheet-iron or copper surface that can be pushed backwards and forwards by an iron rod by the attendant. When the full bailer has been raised completely from the well the flat sliding piece is pushed over the mouth of the orifice, and as the bailer is allowed by the brake to descend, the valve is pushed upwards and the oil discharges into the tub, from whence it flows

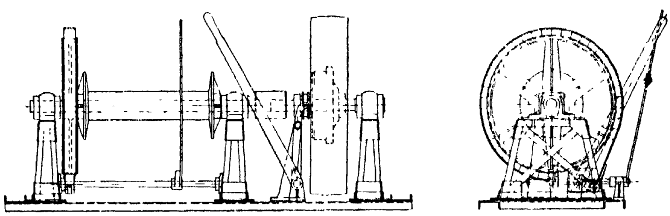


Fig. 118.—Roumanian Bailing Drum.

away in a chute leading from the bottom of the tub to the settling tanks (see Fig. 115).

Recovering Lost Bailers and Ropes.—A bailer lost through the breaking of the wire rope or fracture of the suspension hook is recovered by a hook provided with extending spurs. This tool is lowered on a new rope upon the lost piece, with which it engages and enables its withdrawal. If a bailer is torn asunder it is usual to lower a heavy bar fitted with a succession of hinged protruding dogs, which close in passing an obstacle when lowering, but extend to a horizontal position when the bar is raised, causing them to firmly grip any object into which they are lowered. Fig. 119 shows several types of fishing grabs used for the purpose.

Power for Bailing.—In the Baku oil-fields double-cylinder horizontal steam engines are used for bailing, varying in size from $9\frac{1}{4}$ in. × 14 in. to 14 in. × 18 in.

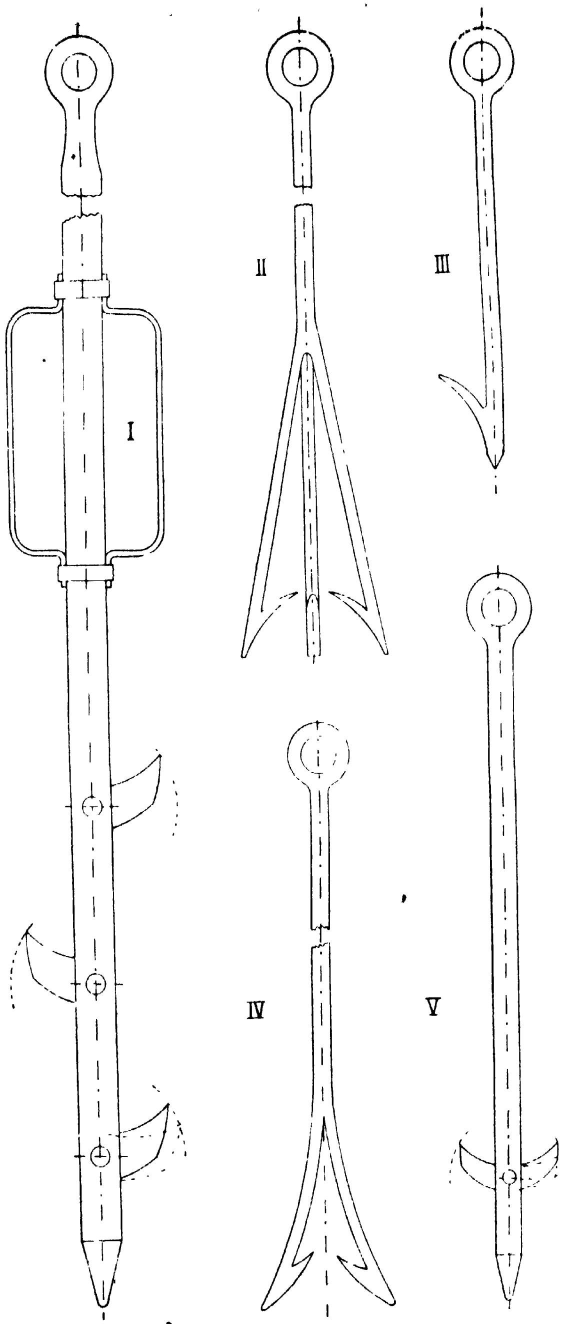


Fig. 119.—Fishing Tools for Recovering Lost Bailers

The larger sizes indicate with 60 lbs. steam pressure as much as 150 H.P., and will raise a 12-in. by 60-ft. bailer at the rate of 1,500 ft. per minute. The smaller sizes are used for bailers up to 8 and 9 in. in diameter. With the steady exhaustion of oil-fields the level of liquid progressively falls, and in many parts of the Baku fields the wells have now only 20-50 ft. of liquid, or are even dry at times, although formerly they had levels measuring in hundreds of feet, and gave as much as 300 tons of oil daily by bailing, but there are few now which will yield even 50 tons daily

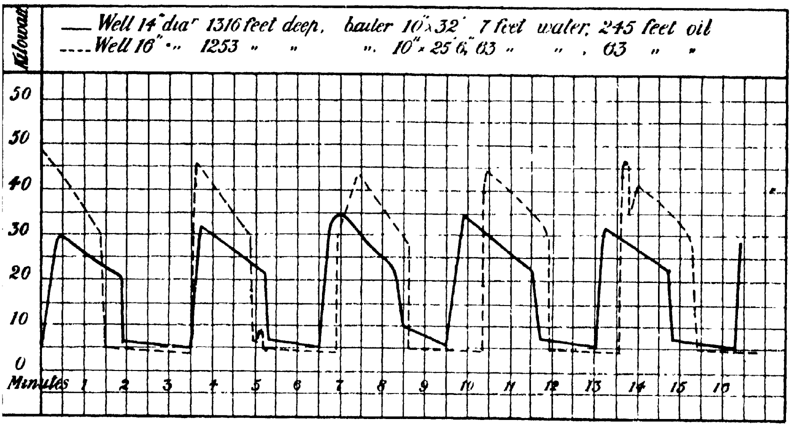


Fig. 120.—Power Diagram of Bailing Well.

Diagram plotted from Data furnished by Recording Wattmeter which intercepted the Current supplying a Motor bailing an Oil Well.

owing to the process of exhaustion which is proceeding. From many wells several times as much water as oil has to be bailed to secure a production.

The general adoption of electrical energy for pumping and bailing enables accurate records of the work to be obtained by the introduction of a recording kilowatt meter. Variations of load give a clue to the state of the well, and time intervals indicate the attention and skill displayed by the attendant. Fig. 120 shows diagrams recorded by two moderate sized wells in the Baku oil-fields of Russia.

Previously to the use of electrical power, recording apparatus

was used in conjunction with bailing drums to ensure the fulfilment of instructions concerning the method of bailing and to check the work of the operator. A diagram from such an apparatus is shown in Fig. 121. Prepared paper is slowly rotated on a drum by clockwork, and the drum shaft connected to the spindle of the instrument by a flexible shaft causes the pencil pressing on the paper to rise and fall as the latter is raised or lowered.

Precautions in Bailing Wells.—When bailing is unavoidable through the presence of much sand with the oil, considerable

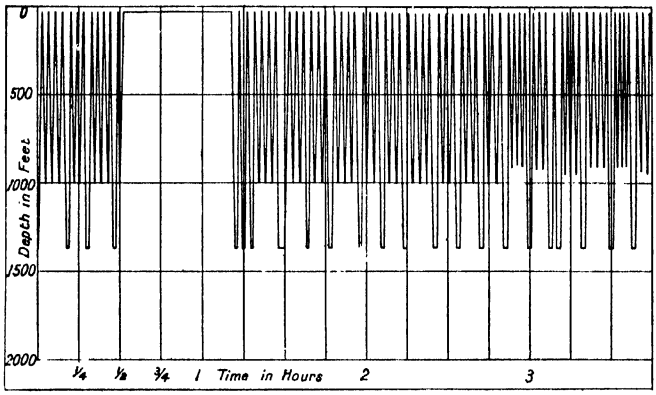


Fig. 121.—Diagram from Automatic Recorder attached to Bailing Drum.

The diagram shows—

1. The number of trips of each within a definite period.
2. The ratio of top to bottom bailings.
3. The level of liquid in well.
4. The time and duration of stoppages.

experience is often necessary to prevent damage to the wells. If a well flows whilst being pumped, nothing serious happens, as the oil flows away from the pump tube or casing heads into the tanks, but when a bailing well shows a disposition to flow the operator needs to act very discreetly for a number of reasons. A discharge of oil from a large diameter well is usually exceedingly violent, and the bailers and wire rope are often ejected from the well with great force if incautiously lowered at a wrong moment. An impending eruption or "fountain" is intimated by a gradually rising level of liquid, and when the oil has arrived

within 100-200 ft. from the surface it is usual to take a few bailers from the top to lighten the column, when the well will flow. During eruption the volume of emitted gas is so great that the attendants have usually to abandon the bailing drum and escape into the fresh air, during which time the brake of the drum is securely fixed. The bailer should be lowered very cautiously after a flow of oil, as there is frequently a large mass of loose falling sand which may settle over the bailer and prevent its withdrawal if it is left stationary for a few moments. In some oil-fields it is no uncommon occurrence for several hundred feet of oil sand to run into the well during a single eruption of five minutes, but so mobile is the mass, if uncontaminated with a proportion of water, that the bailers can be raised full of loose sand at each trip until the hole is cleared.

Eruptions sometimes commence when the bailer is near the bottom of the well, in which case the operator should on no account leave the drum, but keep the bailer in slow motion whilst the well is flowing. If the bailer is left suspended in the well near the bottom it may become buried in sand and be irrecoverable, or lead to a lengthy fishing operation, whilst if raised too high it may be ejected from the well, and both the rope and bailer be totally destroyed.

During the bailing of new wells, whether intermittent spouters or not, a mass of sand, often accompanied by fragments of rock and clay, collect at the bottom of the well, and unless they are periodically cleaned out the free admission of oil is prevented. A collection of sand and clay particles can usually be cleared with the aid of the bailer alone by bailing constantly from the bottom, and raising and allowing it to sink rapidly several times before withdrawal to the surface; the suction action occasioned thereby stirring up the sand and causing it to enter the bailer with the oil on the downward movement. If fragments of clay and rock collect to any considerable extent in the casing they must be cleared with a sand pump.

A new well should never be bailed too rapidly at first, for long experience has shown that the best and longest-lived producing wells are obtained by removing the sand as it flows into the well, by almost constant bailing from the bottom for

a while. This policy is a trial of patience, as in new wells the liquid bailed from the bottom is so supersaturated with gas that the fluid contents of the bailer are nearly all expelled before the surface is reached. When being drawn through the liquid the contents of the bailer are held down by the pressure above, but the moment the bailer emerges from the fluid the confined gas escapes with violence from the oil and ejects most of the oil from the bailer. Bailers are often raised containing only about one-tenth of their capacity of oil, and the almost explosive ejection of the contents of the bailer as it emerges from the liquid can be heard at a distance. This difficulty has been overcome by a bailer with an upper valve that remains open during descent, but closes when the internal pressure exceeds the external. A small subsidiary valve releases the pressure sufficiently to enable the bailer to be emptied in the usual way.

After the inlet of sand has decreased, bailing is conducted alternately from the top and bottom, and the proportion of top to bottom bailings increased until the maximum safe yield is reached, and neither sand nor water accumulates in the well. If any unexcluded water finds admission to the well, bailing must be continued with caution, as the oil sands, unless kept free by much gas, set very hard when mixed with water, and may partially seal the oil source. When such is the case the level of oil falls, and there is a risk that the unexcluded water will increase in volume, making it still more difficult to keep the plug free, and render it necessary to bail more frequently from the bottom to remove the increased quantity of water. Failure to adopt these precautions generally leads to the loss of the well, consequently prudent producers suppress their impatience and rest content with a smaller production for a while.

Cost of Bailing Wells.—As fuel forms the chief expenditure in bailing, the cost of bailing largely depends upon the value of the fuel. The expense of labour, wire ropes, bailers, and stores does not vary much in different undamaged wells. In 1910 the cost of bailing an average Baku well amounted to about £4 ($19) a day, with fuel at 25 copecks per pood (33s. per ton). On an average production of 16 tons a day this works out to about 5s. ($1.20) per ton, 16 cents per barrel.

The average power taken by bailing wells using electric power in the Baku oil-fields in 1908 was about 16 kw. (21.5 H.P.), or 11,500 kw.-hours (15,500 H.P.-hours) per month. With oil at 20 copecks per pood (26s. per ton), the cost of power was 7 copecks (1¾d.) per kw.-hour, and the monthly cost of power for bailing an average well by electricity was 805 roubles (£85), equal to about 2¾ copecks per pood (3s. 8d. per ton) in a well producing 1,000 poods (16 tons) daily.

Swabbing Process of Oil Extraction.—In some oil-fields where the petroleum contains a large percentage of hydrocarbons solid at normal temperatures and pressures, there is a tendency towards the separation and precipitation of the solid paraffins in the wells, as the gas and lighter products are withdrawn or evolved. The deposition of solid paraffin is so great in some oil fields that the wells have to be periodically cleared to secure the free issue of oil from the sands.

In the Boryslaw-Tustanowice oil-field of Galicia the separation of paraffin wax was so considerable when the wells were pumped, following a period of natural flow, that the pumps and pump tubing had to be frequently withdrawn and scraped, and the wells themselves cleared of wax.

Many years ago it was the local custom to swab the wells at intervals by wrapping hemp, belting, or other pliable material round the bailer valves when cleaning out the well with bailers, thereby drawing away by suction wax which clung to the bore-hole sides or plugged the well. It was the observed benefits that wells derived from this treatment that led to the scientific design and general application of a system of swabbing peculiarly adaptable to the conditions of the great Boryslaw-Tustanowice oil-field.

The early varieties of swabs and swabbing plants were of crude construction, and in endeavours to accelerate the speed of extraction with unsuitable plant so many fires originated that the Government issued regulations restricting their employment unless defined safety appliances were attached.

The early swab consisted of a hollow steel barrel, around which was wrapped sufficient hemp or other similar material to tightly fit the well casing when inserted. At the upper extremity was fitted

a flap valve opening to allow the oil to pass through as the barrel was lowered on the rope, weighted above by a sinker bar to hasten its descent. When sufficiently submerged in the fluid, the swab was drawn up at a high velocity ; the internal valve automatically closing, caused the column of liquid above the plunger to be raised to the surface, where it flowed into tanks arranged for its reception.

Modern swabs of 4-5 in. diameter have an internal ball valve, and the packing consists of two or more rubber rings, above and below which, separated by a washer, are steel springs which somewhat relieve the shock on the rubber packings when slight obstructions at the casing joints are passed. Experience has shown that great economy in packers results from the above arrangement as well as by attaching the sinker bar below the swab instead of, as previously, on top, the former position better assuring verticality of the swab during its descent.

As much attention has been paid to the design of machinery to operate the swabs as to the swabs themselves, and producers now realise the advantage of erecting machinery with as much care as is bestowed on winding plant in a colliery. Recent "*haspels*," as the drums are termed, consist of two $14\frac{1}{4}$-in. × 19-in. steam engines direct coupled to a central winding drum, and all mounted on firm concrete foundations. A speed of from 140-160 revolutions per minute, with 150 lbs. pressure steam, is attained, enabling the swabs to be raised at a velocity of about 2,000 ft. per minute. In consequence of the frequency of fires through heated band brakes, the swabs are now lowered by allowing the engines to run with an inverse motion, drawing in air through their ports by a by-pass which is opened to the steam pipe after shutting off steam. Such action throws increased wear and tear on the engines, but little brake power is required.

The "haspels" are operated by an attendant from a central position where he can regulate speed and manipulate the steam admission valve. Coupled to the shaft at one side is a tell-tale device which enables the attendant to observe the position of the swab at any moment. A gong is struck when the swab has descended to the requisite depth, a point decided by circumstances,

and another alarm bell is struck when the swab has ascended to a point near the surface. Powerful foot and screw brakes are attached to prevent running away and overwinding in case of an accident to, or loss of the swab

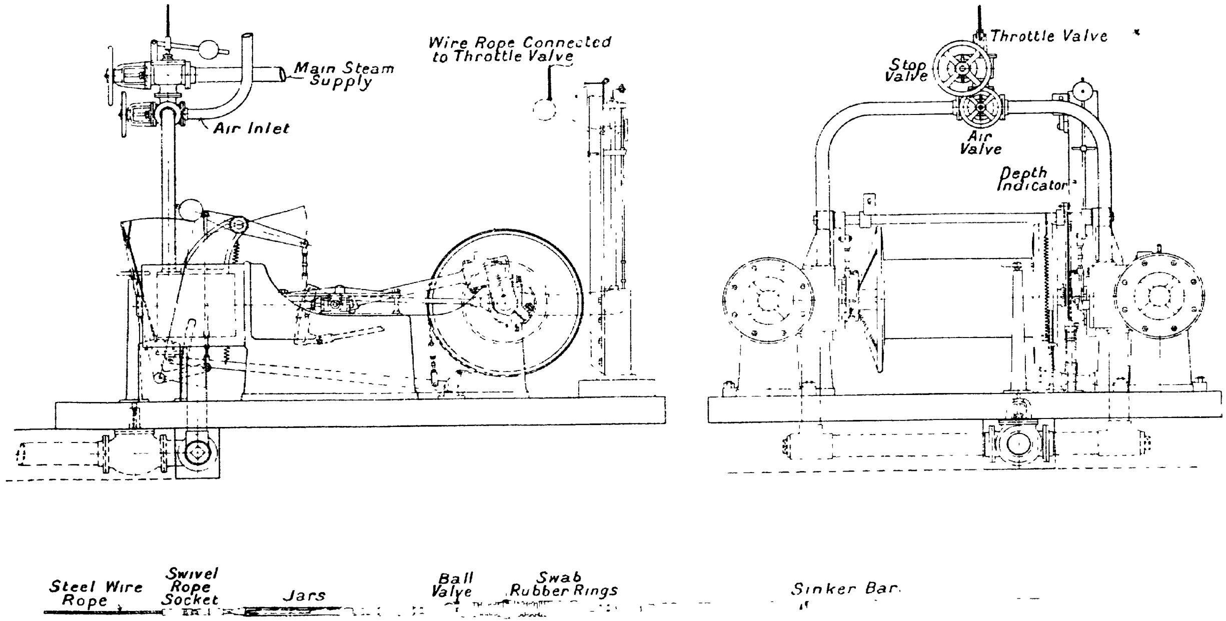
Swabbing is generally conducted in ordinary 4-6 in. diameter casing, but some of the richer firms are inserting in their wells a liner of special tubing with the joints designed to present the minimum of friction and wearing edge. The casing in general use at Boryslaw-Tustanowice is of the "inserted" variety, with swelled female and cressed male end, thus throwing irregular strains upon the packing rings as they pass joints in their ascent.

In practice $\frac{7}{8}$-in. steel-wire ropes are used, and the rubber rings, which just freely enter the casing, require renewing in from one to six days according to the condition of the well and the extent or intensity of swabbing. Highly productive wells are commonly fitted with two "haspels" to avoid any delay in case of one breaking down or needing repairs. These may be placed behind one another or at opposite sides of the derrick; separate chutes in which the oily wire line passes being fitted between the winding drum and the derrick summits.

The well-top equipment is usually very simple. A side outlet pipe is led from the casing to a tank outside the derrick, the rope itself passing some discs of old belting at the exit from the well to abstract as much as possible the oil clinging to the rope, and to prevent oil flowing up into the derrick. The drippings from the rope both in the derrick, from the guide chute, and beneath the drum, are drained into the oil tank, or if solidified swept into the tank at intervals. The exhaust steam from the engine is utilised for heating up the paraffin-bearing crude to enable it to be pumped to central points of storage.

At the point of discharge provision is often made for withdrawing the gas by an exhauster and forcing it under pressure into gas mains.

Experience and practice will alone demonstrate the best manners of using a swab when the necessary plant has been installed. Every well exhibits independent peculiarities, and must be humoured and dealt with as demanded by circumstances; and often patient trials



SWAB AND ATTACHMENTS.

FIG. 122. SWABBING PLANT.

are necessary to discover the best method of treatment. Where there is a high level of liquid some wells give the highest yield by a small submersion of the swab, others by a deep immersion. In both high and low level of liquid individual wells display wide differences in their behaviour according to the speed and number of swabs per unit interval of time. From some wells the best results are obtained by constant, if fewer, runs of the swab per day: in others intermittent operation leads to the highest yield.

Surprising results followed the introduction of scientific swabbing in Galicia. Abandoned wells recommenced producing at a high rate under the influence of swabs, and pumping wells had their yield increased often several-fold by the substitution of swabbing methods. It was quite evident that deposited paraffin wax choked the pores of the oil-bearing sands to such an extent that the contained oil was excluded from the bore hole until it was removed by the suction and disturbing influence of the swab.

Swabbing was originally confined mainly to the large producing wells yielding often by combined flowing and swabbing 100-200 tons (750-1,500 barrels) of oil daily, but the advantages of the system have been proved by demonstration to extend to the smaller producers, and there were, in 1913, many wells 3,000-4,000 ft. deep profitably operated in this way that gave but 5 tons (37.5 barrels), and even 3 tons (22.5 barrels) daily. The level of liquid was often very low, not more than 200 or 300 ft. in wells 4,000 ft. deep.

Improved yields have sometimes been obtained by swabbing in a small column, a 4-in. string of tubing being inserted within the 5 or 6 in. well casing exclusively for the purpose.

No extended employment of the swabbing process has been attempted in other oil-fields than Galicia, but the advantages of this method will one day be realised in several important oil-fields where it is almost certain that improved yields would result from its introduction. The method is naturally mainly restricted to fields where little or no suspended sand accompanies the oil, and its use is excluded from fields where yields do not exceed a few tons daily. It is certain, however, that the initial yield of wells would often be greatly increased, especially where wells do not

flow freely unaided, and the initial gas pressures prevent the free action of pumps.

Considered on a mechanical efficiency basis, the power expended on swabbing is very wasteful. Taking a good well 4,000 ft. deep, with average level of liquid 2,000 ft. from surface, and 12 trips of the swab per hour, at a speed of 2,000 ft. per minute, the following figures are obtained:—

A double-cylinder $14\frac{3}{4} \times 19\frac{1}{4}$-in. stroke engine, with effective steam pressure of 100 lbs. per square inch, indicates about 275 H.P. when running at full power. The average power required during a wind is about $\frac{2}{3}$ the maximum power.

Time of raising swab, 2 minutes. Therefore time of engine operating $\frac{24}{60}$, or power per diem $\frac{24}{60} \times 275 \times \frac{2}{3} \times 24 = 1{,}760$ H.P.-hours.

Average continuous power, therefore, 73 I.H.P., or, say, 62 B.H.P., assuming an engine efficiency of 85 per cent.

Theoretical power required to raise, say, 100 tons daily 2,000 ft. $= 224{,}000$ lbs. $\times$ 2,000 ft $= 448{,}000{,}000$ ft.-lbs. per day.

1 H.P. day $= 33{,}000 \times 60 \times 24 = 47{,}500{,}000$ ft.-lbs.

Average continuous power requirements, $\frac{448{,}000{,}000}{47{,}500{,}000} = 9.5$ H.P.

Efficiency of plant, $\frac{9.5}{62} \times 100 = 15.33$ per cent.

On wells of less yield and higher lift the efficiency would be much lower, but this is of quite secondary importance in view of the possibility of recovering oil impossible by other means.

Allowing 40 lbs. of steam per H.P.-hour, and an evaporation of 12 lbs. water per lb. of oil fuel, the cost in power would be $\frac{62 \times 40 \times 24}{12 \times 2240} = 2.22$ tons of oil daily.

With a price of oil at £3 per ton (\$2 per barrel) this is equal to £6.66 (\$33.30) per day, against a value of oil recovered of £300 (\$1,500), therefore percentage cost of fuel is $\frac{6.66}{300}$ of $100 = 2.22$ per cent. only.

Air-Lift Process of Raising Petroleum.—The successful operation of the air-lift process of raising water naturally attracted attention towards its application to petroleum, but the conditions are quite different with the latter fluid, and many complications

arise when efforts are made to adapt the process to oil. For efficiently raising water, as compared with pumps, it is essential that the direct lift should not exceed 50 per cent. of the total submergence of the air inlet in the water; that is, if there were 400 ft. of water in a well, even if the air were admitted to the rising main at the bottom of the well, it could only be raised with economy 50 per cent. of 400 ft. = 200 ft. With petroleum much the same conditions must exist for efficient working, but there are few oil-fields in the world where there is sufficient oil in the wells to permit of the general adoption of such a process.

The Baku oil-fields, previous to the year 1905, offered an excellent field for air-lifts, as there were many wells of too small a diameter to bail with success with a high level of liquid, and containing far too much sand to allow of pumping, which were capable of yielding from ten to fifty times their bailed productions. In 1899 the first experiments with air-lift in the Russian oil-fields were made under the supervision of the author, and in the first well tested under unfavourable conditions, a daily yield of 40 tons (300 barrels) was obtained from a well which gave less than 8 tons (60 barrels) daily by bailing, whilst the extra fuel consumption did not exceed 1.5 tons (11.5 barrels) of oil daily.

The usual method is to lower a column of 4-in. tubes to the bottom of the well—about 10 ft. of the lowest tube being perforated with ½-in. holes—into which is lowered a 2-2½ in. column. This latter column, which represents the rising main, is sunk until it is submerged to a depth in the fluid equal to at least twice the distance from the level of the liquid to the surface. Suitable attachments are made at the surface, and air is led down the space between the two tubes so that it rises in the centre tube, aerating the fluid in the tube as it enters. The working air pressure approximately corresponds to the pressure due to the weight of the column of liquid representing the submergence, and the supply of air is adjusted to produce sufficient aeration to cause the liquid to flow in a pulsating stream at the surface.

Air-lifts are only started by considerably exceeding the working and calculated air pressure, in consequence of the friction of such a long column of viscous oil, the force necessary to overcome inertia, and the only partial aeration of the column; indeed, the

first discharge after admission of air is exceedingly violent, owing to the formation of a piston of air beneath a long column of unaerated fluid. Variations of the oil level are indicated by fluctuations of the air pressure gauge at the mouth of the well, where it is customary to have one pressure gauge on the compressor side and another on the air-lift side of the valve which adjusts the air admission.

If the fluid in the well falls, the discharge becomes intermittent, but can, if small, be made continuous by increasing the volume of air. There is, however, a limit after which a continuous discharge cannot be induced, and the action either proceeds intermittently, each flow of liquid commencing with a full bore flow of unaerated oil followed by a violent discharge of gas and oil spray, or the discharge takes the form of a constant spray. With the intermittent or spray action the efficiency of the plant falls enormously, as will be seen from the figures below, but, nevertheless, the cost of its working is many times repaid in special cases.

Most Russian wells yield a certain proportion of water with the oil, and often a considerable amount of sand is raised in addition; indeed, its removal, as has already been explained, is usually necessary to keep the well from "plugging." The aeration and violent agitation of oil and water in certain proportions when an air-lift is in operation, leads to the occasional formation of emulsions, some of which defy all simple measures of separation. Some emulsions are discharged from the air-lift in congealed grey masses of the consistency of butter, whilst others are fluid and have the consistency of cream. Many such emulsions liquefy and separate in a few minutes, but some, containing up to 30 per cent. of water, neither separate after lengthy settlement in open tanks nor even permit of any mechanical separation. This latter class of emulsion is not common, and usually producers are not much troubled by its formation.

Great quantities of sand sometimes cause the air-lift to work erratically for a while and may entirely stop its action, but usually the sand eventually gets freed and steady working is resumed. At such times the author has seen a thick fluid containing over 50 per cent. sand discharged for hours before the well was cleaned and normal working recommenced.

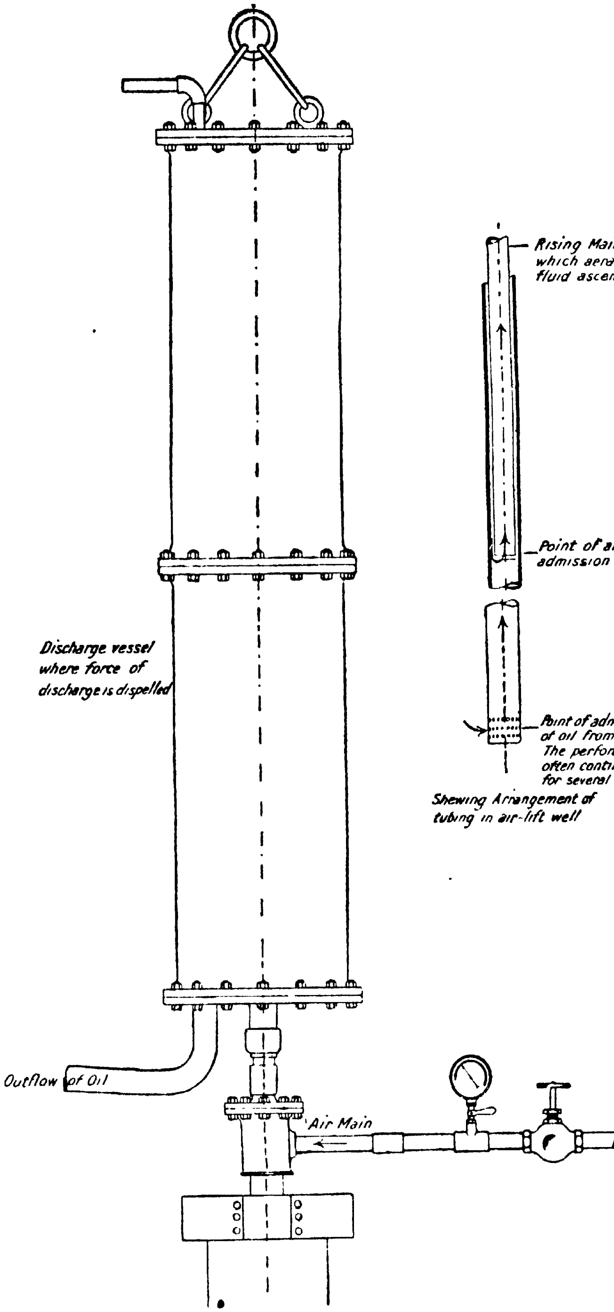


Fig. 123.—Common Arrangement of Air-lift.

The gas accompanying the oil considerably modifies the action of an air-lift, both by diminishing the theoretical air pressure required and by assisting the aeration, and if a packer is attached

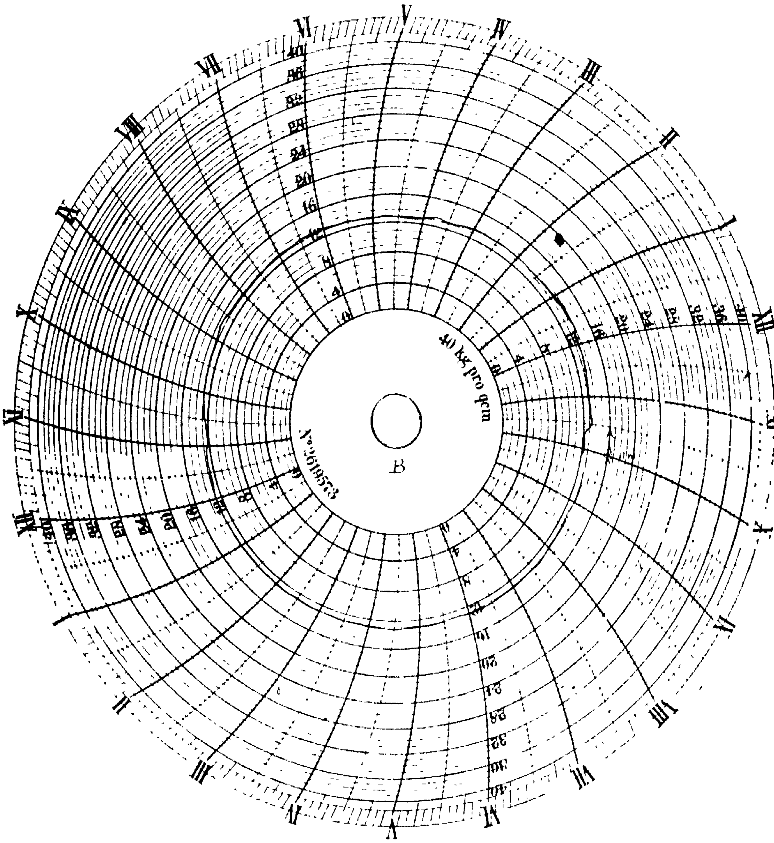


Fig. 124.—Diagram from Recording Gauge attached to Air Pipe connected with Working Air-lift in Oil Well.
Showing normal action when only ordinary quantity of sand is present.

to the tubing in order to compel all the gas to pass with the oil up the rising main, the amount of air required to sustain a discharge may often be reduced considerably.

In some air-lift wells in Bibi-Eibat a diminution of output led to the extraction of the $2\frac{1}{2}$-in. rising main tube, when it was found

to have a deposit over ½ in. thick on the inside of the tubes. The incrustation was chiefly hard carbonate of lime, and was evidently due to a steady deposition from the water accompanying

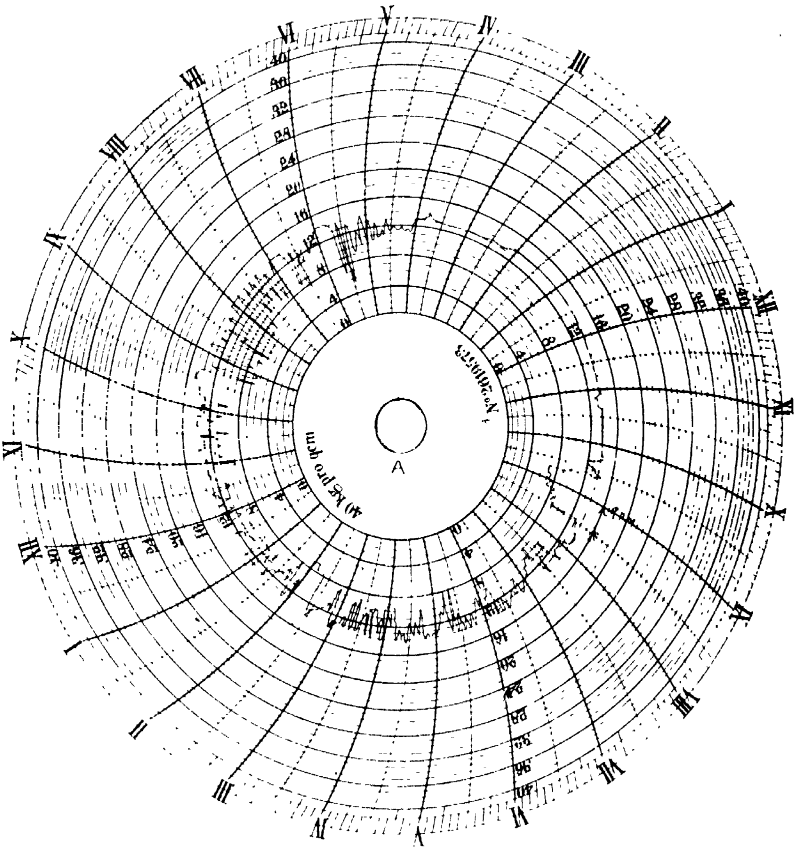


Fig. 125.—Diagram from Recording Gauge attached to Air Pipe connected with Working Air-lift in Oil Well.
Showing irregular action due to sand plugs.

the oil as a result of the liberation of carbon dioxide consequent on aeration and agitation the liquid suffered during its ascent.

The air-lift process can with advantage be employed for raising oil under the following circumstances when pumping cannot be adopted :—

(*a*) When the diameter of the well is so small that the quantity of oil obtained by bailing is much less than the well is capable of yielding.

(*b*) When the influx of sand and water in a deep well makes it compulsory to bail almost entirely from the bottom, consequently considerably reducing the yield.

(*c*) When a bailing well becomes so damaged or deflected that only short, small bailers can be used.

(*d*) When a sufficient head of liquid is maintained to reasonably satisfy requirements as to submergence.

When the best submergence is secured, an air-lift plant will consume about 11-12 volumes of free air per volume of liquid raised, *i.e.*, a well taking 200 cub. ft. of free air a minute will discharge about 16 cub. ft., or 100 gals., a minute. When the liquid falls so as to give only a 50 per cent. submergence, the ratio increases to 1 volume of liquid to 20 or 25 volumes of free air, and in one case under the author's observation, where the submergence was only 35 per cent., the ratio of liquid to air was 1 to 44.

The air compressors used for air-lift pumping are of the compound type, capable of working regularly at 350 lbs., but in which the pressure can be temporarily raised to 500 lbs. per square inch. The usual compressors chosen have an output of 300 cub. ft. of free air a minute at normal speed, and one machine is capable of operating one well under the best conditions of submergence, etc.

The operations of an air-lift can be followed by the use of a recording pressure gauge placed at the mouth of the well. Variations in pressure will be attributed to the correct cause by experience. In Fig. 125 the erratic pressures registered are due to frequent influxes of sand that alternately impeded the inlet of oil as they formed and freed the tubing as they were cleared.

A detailed test made by the author of an air-lift well will give an idea of the general results:—

Depth of 4-in. tubes to bottom of well	1,540 ft.
Depth of inner $2\frac{1}{2}$-in. tubes (air admission)	1,463 „
Working pressure	300 lbs.
Consumption of free air per minute	150 cub. ft.
Liquid discharged per minute	6.25 „
Proportion free air to liquid	24 vols. to 1 vol.
Air compressor, 14 × 7 × 12 in. double acting compound	75 revs. per min.

High-pressure cylinder indicated	8.57 horse power.
Low pressure	8.46 „
Total indicated horse power	17.03 „
Steam engine driving compressor indicated	36.7 „
Efficiency of compressor $\frac{17.03}{36.07} \times 100$	46.4 per cent.
Submergence by calculation	693.8 ft.
Percentage submergence $\frac{693.8}{1463} \times 100$	47.4 per cent.
Direct lift of liquid $1{,}463 - 693.8$	770 ft.
Weight of liquid raised per minute	396 lbs.
Theoretical horse power required to raise liquid	9.24 horse power.
Total efficiency of plant $\frac{9.24}{36.7} \times 100$	25.18 per cent.

The above calculation disregards slight corrections for temperature, atmospheric conditions, etc., and represents, as will be noted, the ratio between the theoretical power required to raise the liquid from the level at which it stands in the well to the surface, and the indicated horse power of the engine driving the compressor, so only neglects boiler efficiency, that could be taken at about 65 per cent. under oil-field conditions. Other tests gave efficiencies varying from 8.5-40 per cent., according to submergence.

Chart No. 126, based on many tests, approximately indicates the working conditions with oils of .880 gravity and a certain amount of water and gas.

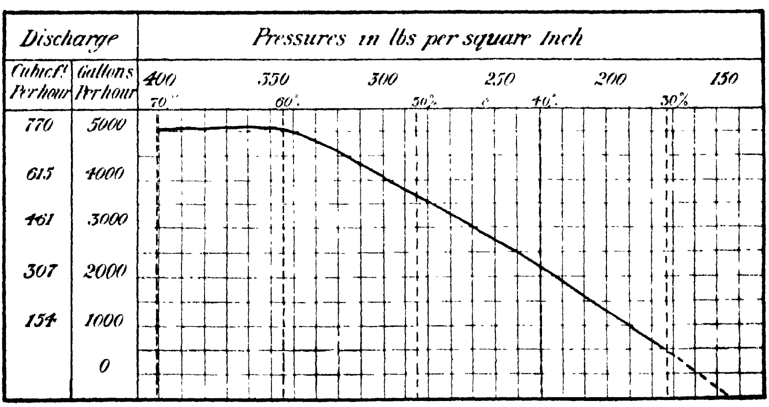


Fig. 126.—Diagram showing Approximate Output of Well Operated by Air-lift at Various Submergences and Pressures ($2\frac{1}{2}$-in. rising main).

These show roughly the following :—

With 70 per cent. submergence	11.75	cub. ft. free air per cub. ft. fluid raised.
„ 60 „ „	11.75	„ „ „ „
50 „ „	14.80	„ „ „ „
„ 40 „ „	26.00	„ „ „ „

The capacities of air-lift plants may be estimated approximately as under :—

2-in. discharge pipe	150 to 270	cub. ft. per hour.
$2\frac{1}{2}$ „ „	260 „ 550	„ „
3 „ „	550 „ 800	„ „

Some published data of air-lift results in the Kern River oil-field of California are interesting.[1] Compressed air, at a pressure of 150 lbs. per square inch, was used for operating some twenty wells. A $1\frac{1}{4}$-in. air pipe and a 3-in. discharge main were used in the wells. Some 550,000 gals. of liquid were daily extracted from the twenty wells, with an air consumption of 4,450 cub. ft. per minute. This represents about 28,000 gals. of liquid per well per diem. The cost of running the plant was estimated at $3.44 per well per day, and if the yield of oil per well be taken at 25 barrels daily, the cost of air amounts to 13.75 cents per barrel of oil raised. The poor ratio of 74 volumes of air per volume of liquid raised is deduced from the above figures.

Compressed Air Systems of Raising Oil.—Quite distinct from the air-lift, the normal action of which is due to the lightening of the column of liquid by aeration, are systems in which air in volume is used to expel the oil. Strictly speaking, the air-lift is no longer pure aeration of the fluid when it commences to work intermittently, and the liquid is expelled in mass by volumes of ascending air, and similarly when oil is discharged in the form of a spray the action is that of an ejector. In the United States the periodical introduction of compressed air to the bottom of wells of small diameter which yield little or no sand is often practised with success, each admission of air causing the well to flow. The quantity of air and periods of admission naturally vary with the diameter of the well, amount of gas, and level of liquid, which latter also determines the pressure of air necessary.

[1] "Petroleum Industry of California." *Loc. cit.*

Compressed air can be employed for raising oil from low-level wells by the following means, introduced into the Russian oil-fields by R. Stirling: A column of $2\frac{1}{2}$-3 in. tubes, near the bottom of which is attached a receiver of enlarged tubing, is lowered into the well so that the larger tubing is entirely submerged in the oil. The lower 10 or 12 ft. of the tubing below the receiver is perforated to admit the oil freely, and at the lower junction between the receiver and tubing is attached a ball valve on a seating. An inch pipe inserted inside the $2\frac{1}{2}$ or 3 in. tubes conveys the air to a point immediately above the valve, so that by admitting the air to the 1-in. pipe, the ball valve is forced upon its seating and the accumulated oil in the receiver and rising main is driven to the surface. A violent escape of air ensues as the last portion of the oil is ejected, and on the release of pressure the fluid from the well rushes into the receiver and rising main from the well. The discharge is made to actuate a device which automatically shuts off the air, whilst another arrangement admits the air at intervals, the periods of which can be adjusted to suit requirements. The cost of such systems far exceeds pumping, both in initial outlay and upkeep, and its employment is restricted to special cases where for some reason other methods of oil extraction are unsuitable.

Causes and Prevention of Premature Decline of Production in Oil Wells.—On pp. 131-46, many causes for the irregular movements of oil are mentioned under the heading of subterranean movements of oil, and it is only intended here to briefly refer to possible causes of premature decline of production, and enumerate some of the means that can be applied to alleviate these conditions. Abundant proof of the advantages of careful nursing is found in the variation in yield of wells under an indifferent and a conscientious, observant field manager. Under the paragraphs dealing with bailing, pumping, and swabbing wells will be found hints known to all practical oil men concerning the treatment of producing oil wells.

Natural exhaustion can have no remedy, but areas conveying that impression can often be revived by methods which are being studied more closely every day. Creation of a partial vacuum, rinsing strata by water, and forcing air into oil beds, have all been tried with partial success, but these can usually only be applied on

a large scale with the acquiescence of a number of producers, some of whom may be antagonistic and decline to allow methods for the general good to include their properties.

Remediable premature reductions of yield of wells may be roughly classified under the following causes:—

1. Caving of strata, sometimes accompanied by damage to casing.
2. Plugging of perforations in casing or slots in screens.
3. Deposition of solid paraffins.
4. Irregular extraction from wells.
5. Waste of gas or loss of earth pressure.
6. Unskilful extraction of oil.
7. Flooding by water.

(1) *Caving or Silting up of Wells.*—Few oil rocks entirely resist the influence of disintegration during the process of oil extraction. Loose sands and those not greatly consolidated readily break down during the process of delivering up their fluid contents, and the material may accumulate sufficiently to entirely or partially exclude the admission of oil to the well. Failure to remove accumulated cavings not only leads to a diminished yield of oil, but possibly to a permanent deflection of the flow of oil and gas to other and perhaps rivals' wells. In some cases such a plug constitutes an actual danger to the well, as in the event of a high level of liquid being maintained behind the casing it may suffer a collapse if the interior is pumped dry, particularly when in a corroded or weakened condition. In some oil-fields large numbers of nodules collect in the wells, and these have often to be broken up with a pick or other tools before they can be raised in sand pumps.

If the method of oil extraction in use fails to withdraw accumulated sediment and it rises to a point where the ingress of oil to the well is obstructed, it is necessary to remove pumps or other appliances from the well, and clean out the material causing the congestion with the aid of bailers, sand pumps, or even light tools in some cases. Where small quantities of sand usually enter the well with the oil forming a consolidated body and there is no lower water, it is a common practice to carry

the well some 30-50 ft. deeper than the oil source, thus leaving a receptacle where detritus may collect and be removed at intervals. This procedure is, of course, impossible when bottom water exists or is feared.

Occasionally earth movements occur of sufficient magnitude to throw out of action a whole group of wells, and even to destroy the casing of some, in oil-fields where large quantities of sand are abstracted with the oil. In such cases oil can often be induced to return to undamaged wells by the introduction of oil or water in large quantities, obstructions being broken down in this way and communication with the well re-established (see p. 140).

The cost of cleaning wells differs greatly, from an insignificant sum to an appreciable charge on the oil production account. A gang of well "pullers" may be able to handle 100 wells in one field and only ten in another. Some figures abstracted from the author's notes indicate in a field of moderate difficulties costs of about $15 per well per month, and about 1.7 cents per barrel of production.

Bailing wells, and those where much caving occurs, may cost much more and entail the use of drilling machinery.

(2) *Plugging of Perforations in Casing or Screens.*—Clean sands free from argillaceous matter rarely obstruct the inlet of oil, also where they are repeatedly covered or uncovered by liquid a permanent pack is not so readily produced as where they are always immersed in fluid. Orifices are quickly plugged if there are thin seams of clay or shale in the sand from which fragments become detached and travel with the oil. Particles of overlying shale or clays often find their way behind the casing to the perforations of screens, and in course of time securely plug them and so exclude or seriously impede the inlet of oil.

Such occurrences can best be dealt with by introducing into the well a sufficient head of liquid to clear away the obstacles. If this fails a pressure should be artificially added with the aid of a pump, either oil or water being used for the purpose. The presence of much argillaceous material of a particularly plastic and obstinate variety may prevent the above operation being successful in the case of screens and readmission of oil can

only be obtained by removing the screen. Obviously their use should be discountenanced under such circumstances.

(3) *Deposition of Solid Paraffins.*—Loss of volatile products that act as a solvent of solid paraffins in crude oil, or the refrigerating effect of the escape of large volumes of gas, often causes the precipitation of solid paraffins. These bodies plaster up the walls of the well, crystallise in the pores of the rock around the pocket of the well, and in course of time cut off the supply of oil to the well unless removed in some way. Reference has been made to the clearing effect of swabbing in the Galician oil-fields on p. 482, and there are cases known where, in ignorance of the true facts, oil-fields of great value have been for years abandoned as exhausted.

Accumulations of wax on pump rods and tubing can be scraped off, and that about the interior of wells can be removed by bailers and sand pumps after being detached or broken up by tools, as it is always a soft substance offering little resistance. Recovered scrapings and extracts are preserved, as they constitute quite a marketable product. The release of paraffins which have clogged the pores of the rock around the well is a less simple and more costly undertaking. Until recent years the full significance of its importance has not been appreciated, with the result that old fields are being reopened by the use of appliances to melt obstructing bodies. Boiling water or steam can be applied with advantage where boilers are available, but more recently electrical heaters have been used. Pennsylvanian contractors were willing to electrically treat oil wells on the basis of receiving for their services one half of any resultant excess production. They had a small portable plant driven by an internal combustion engine, and it is said they made an enviable income on these terms. Solvents of paraffin, such as benzine, can sometimes be used with advantage where other means are less convenient; and mild explosives will often induce a return of oil as a result of shattering and perhaps also warming of the rock. The introduction of heated masses of metal is sometimes beneficial. It has been suggested that recovery of earth temperature after reduction by escaping gases induces re-entry of oil to wells, this latter event being promoted or hastened at times by percolation of water of earth temperature into the partially exhausted oil sands.

(4) *Irregular Extraction of Oil.*—The advantages that accrue to the first wells that reach a new oil source in an area are fully appreciated by operators in many oil-fields. Under the influence of high initial gas pressure, lines of least resistance along bedding or fault planes, joint cracks, etc., develop into feeders to the well, and these established channels are not readily deflected by subsequent development in the vicinity, provided extraction is continuous. Cessation of extraction as a result of faulty plant, neglect, or other causes may result in the diversion of the main supplies of gas and oil to other points of abstraction where more active operations are in force: once diverted, oil may not be induced to return. It is for this reason that the total closure of flowing wells is condemned, and the absolute suspension of production is always regarded with misgivings even when production is suspended on all wells in an area.

Oil wells usually give the best yields and least trouble when steadily pumped night and day at a constant rate ascertained by trial and observation. Below a certain rate of withdrawal, neighbouring wells, perhaps of rival proprietors, may benefit; above that ascertained rate the drag is excessive, and sand is often drawn in, causing stoppages for cleaning the well, and also for frequent renewal of pump parts if the well is pumped. The intermittent action inseparable from bailing is one of the recognised objections to that system, which nevertheless has to be continued in fields like some of the Russian and Roumanian.

(5) *Waste of Gas Pressure.*—Even to-day it is comparatively few that do not view the waste of gas on oil-fields with unconcern. Viscous oils impregnating fine-grained and often partially cemented sands can be little subjected to the influence of gravity where the strata are inclined at but a few degrees from horizontal. It is therefore quite apparent that in the absence of water it is upon the gas alone that reliance must be placed for the expulsion of oil from the rock. L. G. Huntley affirms that in many of the American oil-fields the safety of the field from invasion by water is dependent upon the retention of a certain gas pressure,[1] and he refers to a disregarded

[1] "Possible Cause of the Decline of Oil Wells," L. G. Huntley, Bureau of Mines, 1913, Washington, U.S.A.

Oklahoma law requiring the retention of 50 per cent. of the open flow of wells.

Some loss of gas without performing work is unavoidable, but deliberate waste on a large scale is no longer justifiable in any but perhaps a few cases where its control is difficult and dangerous, and its intimate mixture with the oil prevents any isolation. The greatest loss of potential energy undoubtedly arises from the excessive number of wells sunk in a definite area, each of which, in most cases, daily belches forth into the atmosphere, gas liberated without performing more than a fraction of its possible power.

A witness in evidence before an American Commission, referring to the uncontrolled waste in the Glenn pool of Oklahoma, submitted that in this one field $11,250,000 was spent in sinking 2,500 wells when 706 should have sufficed to drain the area, costing only $3,177,000. The wasteful development following local excitement resulted, he contended, in the price of oil falling from $1.31 to 38 cents and even 20-30 cents per barrel in special cases, and the value of properties being reduced by more than 50 per cent.

Perhaps the most effective way of utilising natural gas is to allow wells to flow naturally by heads where possible, after the insertion of a diameter of casing suitable to their requirements. In these circumstances oil accumulates in a supersaturated state till the column is lighter than the atmosphere, when it starts flowing, the rate of expulsion increasing rapidly after once the oil is put in motion on account of the expansion of gas following reduced pressure. This procedure is only possible when the wells are widely spaced so as to avoid the influence of draining on the sands by rival operators less scrupulous about waste.

Gas pressures are always referred to in terms of atmospheric pressure, but the imposition of a partial vacuum is equivalent to an increased pressure of equal amount, in fact it is more in the case of most petroleums, as at earth temperatures diminished pressure results in the volatilisation of light products. Gas so formed in the earth is an agent of transportation for the oil, and that such volatilisation does take place under reduced pressure is clearly shown by the increased percentage of condensable products in gas extracted from wells under a partial vacuum.

Operators frequently take advantage of a partial vacuum when signs of exhaustion appear, and in nearly all cases improved yields of oil result. Oil-fields producing asphaltic oils of light density can have their life greatly prolonged by using vacuum pumps or exhausters on the wells, but where paraffin oils exist, the increased deposition of wax may more than neutralise any improvement resulting from diminished pressure. The use of vacuum pumps by one operator is quickly reflected in the returns of neighbours not so equipped where wells are not widely spaced, consequently the introduction of the system is closely followed by its general adoption.

Exhausters can be designed as single units operated by the walking beam or jerker line that transmits motion to the pump, or where wells are not too widely spaced, by the installation of a central exhauster connected to pipes that lead to the wells. It is scarcely necessary to emphasise the importance of air-tight fittings about the wells for the maintenance of a considerable vacuum without great expense of power.

(6) *Unskilful Extraction of Oil.*—Whatever the process of extraction, judgment gained only by experience and study of local conditions can decide on the best manner of performing the work. Whether the well be pumped, bailed, swabbed, or operated by air-lift there is a speed of extraction or a periodicity of working that is best adapted to each case. Oils betraying a disposition to deposit solid hydrocarbons require especial attention to ensure a maximum safe rate of yield. In some wells the level of oil cannot be reduced below a certain point without eruptions of gas, inrushes of sand, or influx of water, all of which can be avoided by the maintenance of a correctly ascertained speed of working. Some wells that become exhausted by pumping or bailing give best results by being operated several times daily, others give the highest yields when worked one or two days weekly, a high level of liquid collecting in the interval of repose.

Experience has shown the wisdom of not reducing the level of liquid below the oil-bearing stratum in fields where paraffin oils occur, and means have been devised, and are sometimes

put into execution, for automatically throwing a pump out of action or returning oil to the well when a certain prearranged level from the surface is exceeded. Even in fields yielding asphaltic oils it is usual to refrain from drying up the well, in the knowledge that the outflow of oil is in some way restricted by such exposure, due possibly to the deposit of mineral salts and accumulation in the sand pores of oils that have lost their most volatile contents and become more viscous.

Undoubtedly differences of opinion exist concerning the relative merits of continuous and intermittent extraction. There are numerous cases where intermittent pumping is practically enforced by the small yield of wells if needless wear and tear of machinery is to be avoided. Tests conducted by the author in one large oil-field, where the average daily yield of wells by pumping was between three and five barrels, indicated that a somewhat smaller production resulted from pumping groups of wells once every few days, instead of several times daily. It was, however, doubtful whether the loss of production was equivalent to the saving effected in labour and wear and tear of machinery. The subject must be approached with caution, and with no preconceived conclusions if losses are to be avoided, as the subject has been little investigated, and the problem is bristling with difficulties and possibilities.

In another field, where bailing and pumping were practised side by side, and most wells suffered a serious fall of level when operated, some inconclusive tests were conducted. As in the other examples, an immediate loss of oil was sustained, but whether the ultimate yield of wells would be diminished it was impossible to say.

Increased yields are often obtained from groups of wells by rapid pumping from one where, perhaps, water is found in excess; or the suspension of one or several wells will lead to an increase of production from the others, corresponding with the output of the stopped wells. Leaks in rising main of pumps, worn cup leathers, and other neglected details may be a source of loss.

(7) *Flooding by Water*.—This common cause of premature

loss of wells and oil-fields is dealt with elsewhere in detail under exclusion of water, etc.

Encroaching water must not be confused with moderate proportions of indigenous waters that often favourably influence the percentage extraction of oil from the sands by the rinsing action they set up. Few fields disclose an entire absence of water, and the greatest gushers on record have often been characterised by a fair and fluctuating percentage of water, either emulsified or not. In almost every oil-field the extracted oil is contaminated with a certain proportion of water, either indigenous to the oil-bearing stratum, or admitted through the medium of faulty wells from upper or lower water-bearing strata. Even if quite obscured, settlement in tanks nearly always discloses the occurrence of water, but such quantities need not be viewed with alarm, and, as explained, may even be welcomed.

From 5-20 per cent. of water is common in oil-fields, and large producers often give as much as 50 per cent. An examination of 450 wells in the Coalinga oil-field of California showed 21 per cent. making 10-50 per cent. of water, and 4.4 per cent. making over 50 per cent. of water.[1]

Emulsions and their Treatment.—Mixtures of oil and water, when agitated in the presence of fine inorganic material such as sand, clay, or precipitated mineral salts, readily form emulsions. Some quasi-emulsions readily break up on short or prolonged settlement, but others do not, and are an endless source of anxiety and expense to oil-field operators. Quasi-emulsions of the simple variety, and obstinate emulsions have been observed repeatedly in air-lift plants, the intimately mingled oil and water being expelled at times in masses of the consistency of vaseline or butter at summer temperatures, but the latter always quickly disappeared on settlement in tanks. This solid mixture appeared generally during intermittent action of the air-lift, and at a point near the junction of oil and water such as is well defined during such action. Thus oil is first expelled, then the emulsified material, followed by water which had separated out during the period of quiescence. Less docile emulsions frequently

[1] "Petroleum Industry of California." *Loc. cit.*

appear in many oil-fields, and in some enormous quantities of such material have been thrown away in desperation.

Engler has referred to the occurrence of refractory emulsions in the Tarnawa Dolna-Wielopole field of Galicia, where oil is recovered from fissures in Oligocene sandstone at depths up to 700 metres. Gushers were common, but after about a year the wells turned to "Marast," a thick brown mass that only burned when mixed with other oil. It usually collected, when placed in vessels, at the junction of the oil and water, and acquired such density that small stones would not pass through it. This emulsion was found useful for road dressing.

Difficulties through emulsions chiefly occur in the heavy oil districts, such as California, where dehydrating processes have been forced upon operators to save millions of barrels of oil from being wasted; but the troubles occur at intervals in other fields where oils of light density are abstracted. Bakû well shave at times yielded as much as 150-200 tons (1,050-1,400 barrels) of repulsive-looking, refractory emulsion, although the density of the crude oil is only .880. Lengthy settlement failed to bring about separation in some cases, but in others a partial separation occurred and some oil was recovered by treating them.

An electrical process has been evolved by Messrs Cotterell & Speed that has given satisfaction where erected, and for which is claimed a high efficiency in purification at moderate cost. The principle is based upon the property of a high-tension current to pierce a dielectric such as is produced by globules of oil, and to release their water and mineral contents in an effort to establish connection between two electrodes. Once the encircling films are broken, water chains are formed enabling freed oil particles to coalesce.

Chief interest lies in the electrical element, which consists of a vertical cylindrical vessel on which are mounted two concentric electrodes composed of taut wires strung from an upper and lower spider or frame. The central electrode is built on an insulated frame attached to a vertical shaft rotated by bevel gearing, and carefully insulated, whilst the outer electrode is fixed to the sides of the vessel and is earthed. In the event of a short circuit causing

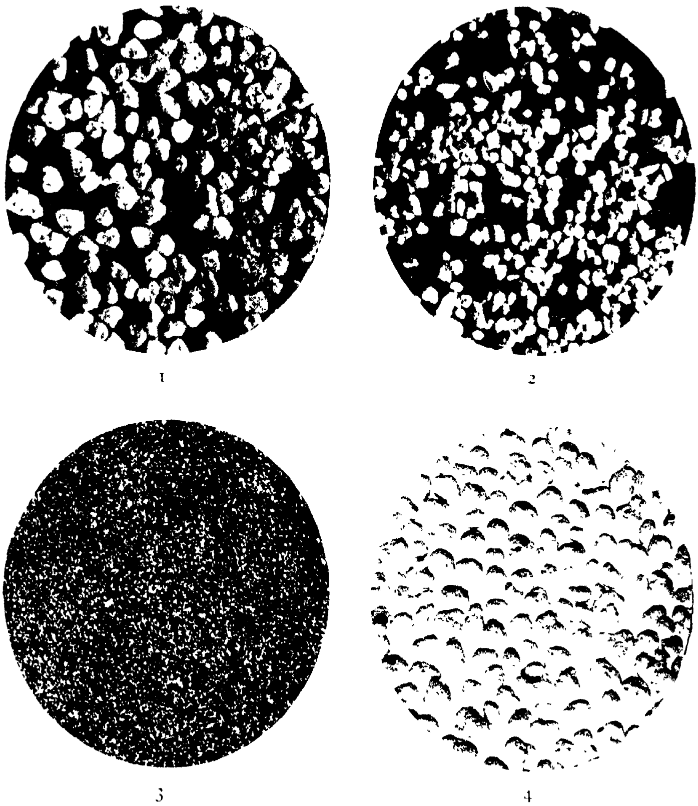


FIG. 127.—SCREENED EMULSION SANDS.

1. Sand detained by 150 meshes to the inch.
2. Sand detained by 200 meshes to the inch.
3. Sand that passed the 200-mesh screen.
4. Sand Balls composed mainly of the finest sand (3) formed during agitation with kerosene in endeavour to wash out heavier oil, and so break up emulsion. Continued shaking produced less regular but larger lumps, perhaps up to 100 times the bulk.

1, 2, 3. Magnification, $10\frac{1}{2}$ diameters. 4. Magnification, $2\frac{1}{4}$ diameters.

[To face page 504.

the rupture of a fuse, steam is automatically introduced to suppress any fire. For heavy viscous oils the vessel is heated by steam and clad with some non-conducting material to conserve heat.

An electrostatic pressure of from 10,000-15,000 volts is applied to the inner electrode, and the observed tendency of globules of water to form chains is defeated by the rotation of the electrode causing these strings to break after being lengthened, and incidentally, at the same time, increasing the efficiency of the apparatus, and decreasing the consumption of power. Quasi-emulsions are abstracted from the oil by its passage through a water trap and filter prior to its introduction to the vessel; and subsequent separation of oil and water is effected by passing the treated mixture into a second water trap.

It is claimed that each unit treater will treat from 50-150 barrels (7-21 tons) a day, according to the gravity of the oil and amount of water, and that the power consumption is about 37 kw.-hours per day—29 kw.-hours for the treatment, and 8 kw.-hours for the power of rotation. At 2 cents (1d.) per kw.-hour the cost per unit is therefore about 75 cents (3s.) per treater per diem, or say $\frac{75}{100}=0.75$ cent per barrel on the basis of 100 barrels per day treated.

Other systems used in California are described by Messrs Paine & Stroud.[1] One method suitable for the least obstinate emulsions provides for the passage of oil through a finely perforated pipe in the base of a tank containing some 10 ft. of water. The water is heated to about 200° F. by a steam coil, and in the passage of the emulsion through the water separation is effected and the oil accumulates on the surface and is led away.

Another system is described in which the emulsified oil is raised to a temperature of from 375°-425° F. by passage through retorts. The heated oil and vapours are led into an evaporator where the oil flows down in a fine film, allowing the escape of water vapour; evolved vapours are led off to a condenser after both these and the escaping oil have been used for heating

[1] "Oil Production Methods," by Paine & Stroud, Western Engineering Co., San Francisco.

up incoming crude material. The cost is said to be between 3 and 4 cents per barrel (10½d. to 1s. 4d. per ton).

Commingled, even intimately commingled, mixtures of oil and water can be separated by heating. Either steam directly admitted to such oil, or passed through coils in the base of a vessel through which the oil is passed will effect separation, and for this purpose exhaust steam can often be economically employed, as a temperature of about 200° F. is ample. Any evaporated spirit can be condensed by conducting the output of the vessel in which the heating is performed to an atmospheric or water condenser. Spirit so produced is sometimes returned to the crude oil to facilitate separation. Centrifugal separators have been used with success with some oils.

True emulsions, however, are only formed in the presence of a finely divided third body insoluble in both the oil and the water, and they are due to the formation and collection around the particles of oil of a coating or pellicle that prevents the globules of oil from coalescing. Under the microscope the solid particles may be observed encircling the globules of oil. Emulsification apparently depends chiefly upon the size of the particles involved, and gas is naturally the agent of agitation in oil wells that develop this feature.

An emulsion from a Romany well in the Baku oil-fields of Russia, containing much fine sand (see 3, Fig. 127), was most easily de-emulsified by methylated spirit, and doubtless any solution in which both oil and water dissolve would break down emulsions. Sulphuric acid caused partial de-emulsification, but, singularly, nitric acid and water immediately and completely restored the emulsion. A cold water extract of the emulsion yielded :—

Magnesium - - -	.103 grammes in 500 c.c. of water.
Sodium - - -	1.420 „ „ „
Chlorine - - -	2.200 „ „ „
Total solids - -	4.250 „ „ „

The solution on evaporation contracted a persistent soapy-looking film which, on heating further, blackened, got white again, and fused ; the loss on ignition being 11.7 per cent. There was

no evidence of aluminium till after evaporation and ignition, and solution in HCl, so probably it is in the form of palmitate of alumina. In both cold and hot water solutions there was evidence of a soap and organic matter, and some curious crystals were formed on evaporation after treatment with alcohol, but not enough for chemical examination.

Emulsions contain usually from 30-60 per cent. of water, and the subject of dehydrating the heavy oils of California has assumed such importance that extended investigations have been undertaken to discover a cheap means of treatment.

Emulsified oils are often known in the American oil-fields as "*roily*" oils.

CHAPTER XI.

OIL-FIELD EQUIPMENT.

Selection of Power—Steam Boilers and Accessories—Theory of Oil Combustion—Steam Engines—Internal Combustion Engines—Electric Lighting—Electric Power—Design and Construction of Pipe Lines—Submarine Pipe Lines—Pumps—Measurement and Storage of Petroleum—Cause, Prevention, and Extinction of Fires—Mechanic Shop and Buildings.

Selection of Power.—To one unacquainted with oil-field work the selection of the best kind of power to be employed for prospecting purposes may appear of little concern, but in practice much consideration should be given to the subject unless disappointment is courted. Steam is, and always has been, the favourite source of energy, chiefly on account of the simplicity attending its generation and utilisation, as well as the flexibility of the steam engine. No motive power requires less skill and attention than a steam engine, nor will any motor better withstand the rough treatment to which machinery is usually subjected in pioneering work, where skilled artisans are rarely available.

When prospecting is undertaken in a region far removed from railway communication or even macadamised roads, the transport of a heavy steam boiler is a costly matter, and one naturally considers other and more compact sources of motive power, especially if fuel is not locally procurable. If water and either wood, coal, oil, or gas fuels can be obtained locally at a reasonable cost, a steam engine and boiler should be certainly chosen for prospecting unless the transport difficulties are almost insuperable. Where water is scarce and solid fuels are expensive and perhaps difficult to obtain at any cost, the question of internal combustion engines is naturally raised, and these may with advantage be used in certain circumstances. For reasons which are given elsewhere (see p. 526), internal combustion engines are not suitable for all systems of drilling, and where their employment is practically unavoidable, it may be advisable to

change the form of rig to suit the type of power. Electrical power is usually removed from the province of probability for prospecting, owing to the absence of available sources of power, and the high initial outlay a generating plant implies before the commercial worth of a district has been demonstrated. Where, as is frequently the case, small quantities of crude petroleum can be extracted from hand-dug pits, certain types of oil engines can be employed with suitable drilling apparatus.

Not quite the same considerations influence the choice of power on a working oil property as on a prospecting venture where a certain amount of uncertainty as to the future exists. The scarcity or prevalence of fresh water or water of any character in the vicinity largely influences the choice of power, although such features as means of transport, character of ground, and topography have an important bearing on the case. In many oil regions fresh water is very scarce although there is an abundance of salt water, whilst in other cases local waters are so contaminated with salts in solution and organic impurities that their direct employment in steam boilers is attended with great risk.

The relative cost of wood, coal, and oil, and the existence or the absence of natural gas affects the problem of power considerably, whilst the system of drilling dictated by local conditions also influences the choice of power. The climatic conditions, distance apart of individual wells, and average time taken to complete wells in the district also enter into one's calculations when deciding upon the nature of power to be adopted. Sometimes conditions justify the installation of evaporators for the production of fresh water from sea or other bad water, for employment in boilers, consequently brief particulars of such plants are given in a subsequent paragraph. The use of electrical power for oil-field work is extending, but its general adoption has been delayed by the disinclination of manufacturers of electrical plant to study the peculiar duties the motors have to perform whilst ensuring safety, economy, and reliability.

Steam Boilers and Accessories.—Where there is a moderate supply of fresh water, the use of a multitubular portable boiler is customary for oil prospecting work. Special portable boilers, often known as the Colonial type, are made in sizes for evaporating

from 800-1,500 lbs. of water per hour, and they are provided with an extra large fire-box suitable for burning wood or liquid fuel if occasion demands. They should be furnished with injector, feed pump, and forced draught jet, and be sent out with spare boiler tubes, also fire-brick furnace attachments and liquid fuel burner, if the burning of liquid fuel is probable. Lagging to reduce radiation losses should not be omitted; fusible plugs should also be included, and high-class fittings provided throughout.

For an ordinary American cable or Canadian drill, a boiler of

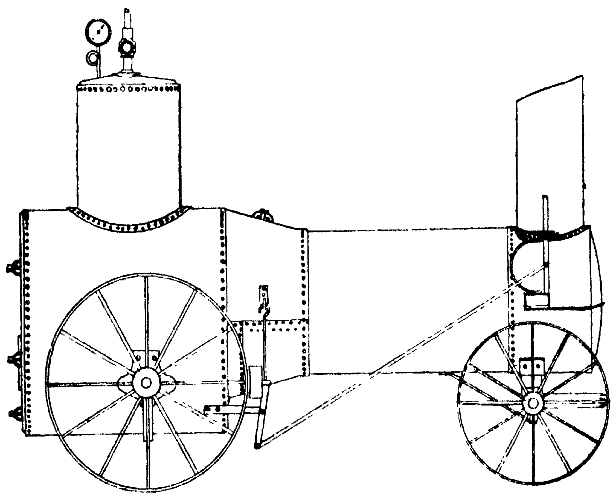


Fig. 128.—American Type of Portable Oil-Field Boiler.

1,000 lbs. per hour capacity under normal working is sufficiently large, but where the climate is very cold, the wells deep, or additional steam is required for subsidiary power, as pumping water or driving electric light motor, a larger boiler should be used. When using rotary water-flush systems of drilling, where the casing or tools have to be rotated, and a pump worked under high pressure at the same time, a boiler should be used capable of evaporating easily 1,500-2,000 lbs. per hour.

The following are particulars of portable boilers made by an English firm and largely employed for oil prospecting and development all over the world.

PARTICULARS OF DRILLING BOILERS.

Heating surface - - -	200 sq. ft.	241 sq. ft.	254 sq. ft.	294 sq. ft.
Grate area - - - -	10.14 „	12.25 „	12.25 „	12.25 „
Evaporation in lbs. per hour -	1,000 lbs.	1,100 lbs.	1,150 lbs.	1,320 lbs.
Weight with chimney, wheels, fittings, undergear - -	77¼ cwt	97 cwt.	97 cwt.	104 cwt.

The boilers will evaporate about 8-9 lbs. of water per lb. of average coal. When wood is used the boilers consume between 3 and 6 cords of wood a day of twenty-four hours, or 13.5-27 cub. ft. of stacked wood per 1,000 lbs of steam. When oil-fed the

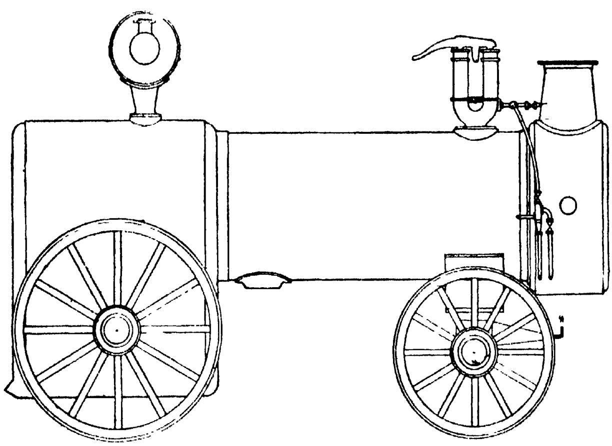


Fig. 129.—English Type of Portable Oil-Field Boiler.

boilers will consume from ¾-1½ tons (say 5½-8½ barrels) of oil per day of twenty-four hours, or if gas is used somewhere about 2,000 cub. ft. per hour should be allowed. Such multitubular boilers will evaporate about 5 lbs. of water per square foot of heating surface, and consume about 18 lbs. of coal per square foot of grate surface per hour. Their thermal efficiency is about 63 per cent. Figs. 128 and 129 show typical oil-field boilers.

Portable boilers are generally placed as near as possible to the engines, which latter are usually sufficiently far from the bore hole to avoid ignition of any ordinary quantity of gas which may be evolved during drilling. If strong gas is suspected the boilers

must not be located near the well, and always to leeward of prevailing winds.

One common type of American boiler is known as the Californian boiler. It consists of an ordinary cylindrical tubular boiler arranged so that when mounted on masonry or iron framework the firing is performed beneath, the flue gases after passing the length of the boiler being led through the tubes from the back to the point where the smoke stack is located. These boilers are made in sizes from 25-45 nominal horse power, and are largely used in the oil-fields of the States. Needless to say, the multitubular type of boiler must never be used with salt or dirty waters.

In many oil regions the use of high evaporative boilers is prohibited by the absence of fresh water, and either locally obtained saline water or sea water has to be used. In such cases, steam is usually generated in either Cornish or Lancashire boilers at a pressure which should not exceed a maximum of 60 lbs. per square inch. Such boilers of sufficient size to supply steam for even one drilling well are too large and heavy for portability on wheels, and they are either set in a masonry structure, or in a sheet-iron frame which can be lined with fire-brick, so that the flue passages pass along the bottom and sides of the boilers.

A fixed boiler of the above description has many disadvantages, apart from its weight and size, which render its transportation expensive when oil prospecting is proceeding. Its erection is not only expensive, but much time is occupied in the work. Its range of effective action is limited, as condensation, especially in cold climates, makes it impossible to supply sufficient steam at the required pressure for a radius exceeding a certain limit. The evaporative efficiency is low, especially as a heavy scale accumulates after a short period under steam, and about 30 per cent. of the water fed to the boiler has often to be blown off to keep the density within the limits of safety. Then, in addition, there is the ever present danger of a collapsed flue or burnt plate, either through inattention to regular blowing off, or to the safe period between successive stoppages for cleaning being exceeded.

Caspian sea water was, until the use of electricity commenced in 1900, practically the sole source of power in the Baku oil-fields of Russia, and even in 1908 three-fourths of the power was generated

in Lancashire boilers fed with sea water. Practically no fresh water is to be found within many miles of the Apsheron oil-fields; indeed, the 100,000 inhabitants of Baku were, until 1914, provided almost entirely with distilled water obtained from evaporators. The defects of such a system have long been recognised, but as the wells are located near together, and it is inadvisable and illegal to have a boiler near an oil well, the continuation of the system is more excusable than would otherwise be the case. Nevertheless, the waste of fuel as a result of such defective steam systems was enormous, and the rising prices of crude oil inspired producers to seek cheaper sources of power. The author has found that the average nominal 45 H.P. Russian Lancashire boiler, 6 ft. 6 in. diameter by 30 ft. long, and heating surface of about 750 sq. ft., will only produce, using sea water, less than 10 lbs. of steam per lb. of crude oil fuel having a calorific value of 20,000 B.T.U. per lb., less than 50 per cent. thermal efficiency. The loss in distribution through long steam mains on account of friction and condensation is so great that when the average air temperature is 80° F., the consumption of fuel is between 5 and 6 lbs. per B.H.P. per hour, whilst in winter the consumption exceeds these figures.

So excessive is the wear and tear on boilers using sea water, and so great the waste of fuel as a consequence of its use, that the author's firm in one case installed, with considerable success, where there was no fresh water, an evaporating plant, and used fresh water in multitubular boilers on an oil property where the operations extended over several square miles. Where sufficient gas is available for fuel, and there is an ample supply of sea water, this course can always be successfully introduced.

Where only sea water is available, plain cylindrical vessels have been used as boilers, the heat being applied by firing below and leading the gases along the sides of the vessel also. Such boilers admit of easy cleaning, but their evaporative efficiency is exceedingly low.

In certain Russian, Roumanian, Galician, Texan, and other oil-fields, where the wells are placed close together, steam boilers are arranged in batteries of six, twelve, or more, the steam being conducted about the properties by well-insulated mains. The existence of large quantities of gas in some oil-fields has led to stringent

laws being enforced regarding the position of boiler-houses and their relation to oil wells; steam is, as a result, often led long distances with consequent considerable losses.

Liquid Fuel Installations.—Steam boilers on oil-fields are almost universally fired by oil if gas is not available, but perfect combustion can only be accomplished by pulverising or atomising the oil into minute particles so that it can become intimately mingled with air from which it derives the necessary oxygen. This end is achieved by some form of atomiser, sprayer, or burner, as it is variously termed, that enables a jet of steam or air to induce a suitable subdivision before ignition. The most popular burner for oil-field work is that operated by steam, as, being simple in construction and free from complications, its use can be recommended anywhere.

For various burners are made claims usually extravagant and more or less imaginary, unless designed to suit some particularly viscous oil or to overcome some other local difficulty. Perfect combustion ensues in all scientifically designed burners and little more can be achieved beyond general simplicity and reliability. If pressures below 60 lbs. are used for atomisation some special kind of burner is necessary.

Although the kinetic energy of a steam jet exercises a powerful disintegrating effect on oil and induces a fierce inrush of air, the steam itself is a non-supporter of combustion, and where early ignition and high temperatures are desired, an air burner is to be preferred. Those constructed for low pressure air, say 3 lbs. per square inch, need much more careful designing than those intended for pressures of 50-60 lbs. Atomisation is much less perfect with air, but oxidation is rapid and the heat intense.

Admiralty and mercantile marine requirements have led to the introduction of a type of pressure burners to avoid the loss of water sustained in steam burners and the need of large auxiliary plant if air is employed. Pressure atomisation is accomplished by forcing well-strained, filtered, and heated oils through fine annular or circular orifices of such design that the ejected oil is broken up into a veritable mist, thus producing a highly combustible vapour-like body that readily burns in the presence of forced draught. These burners entail more attention than other varieties and are

consequently little used in oil-fields, as the slightest extraneous matter will choke the fine orifices that are an integral part of such burners.

Steam burners may be considered to consume from ¾-1 lb. of steam per lb. of oil burnt, and usually in practice the consumption lies between 5 and 10 per cent. of the water evaporated, but may rise to as much as 12-14 per cent. in ill-designed plants. Air burners require from 2-4 lbs. of air (26-52 cub. ft.) per lb. of oil burnt according to the make of burner and the pressure employed. High pressure air burners, say 60 lbs. per square inch, take about 1.5 lbs. of steam for compressing the air per lb.

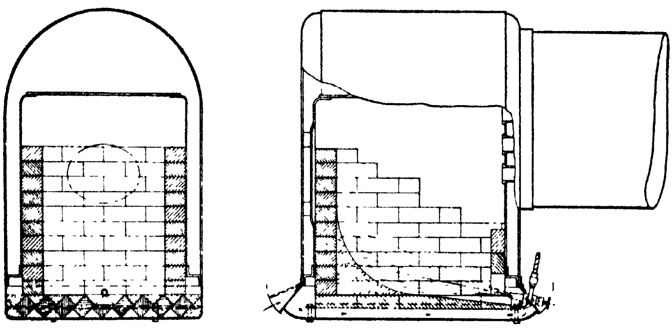


Fig. 130.—Arrangement of Brickwork in Furnace of Portable Boiler for Burning Liquid Fuel.

of oil burnt; low pressure burners are estimated to consume only 0.5 lb. of steam per lb. of oil. Pressure burners take power for compressing the oil and driving the fan for forced draught, also heat for heating the oil.[1]

Liquid fuel furnaces must be lined with fire-brick when the flame is likely to impinge direct upon metal. Portable multitubular boilers have their fire-boxes lined and often an arch placed beneath and in front of the tube plate, thus providing an incandescent chamber that re-ignites extinguished oil, and ensures complete combustion before the heated gases enter the tubes. The burner is usually placed in the ash-pan, or in an orifice just

[1] For particulars of liquid fuel burners, etc., see Booth's "Liquid Fuel and its Combustion."

above, where air admission can be adjusted by a grating. A much better system was initiated by Thompson and Hunter who placed the burner at the back of the fire-box, allowing the flame to impinge on the front plate, when it was deflected back. There is then no danger of overheating the tube plate. The only objection to this arrangement is the inconvenient position of the burner for regulation (see Fig. 130).

Lancashire or Cornish boilers have a furnace front fitting that

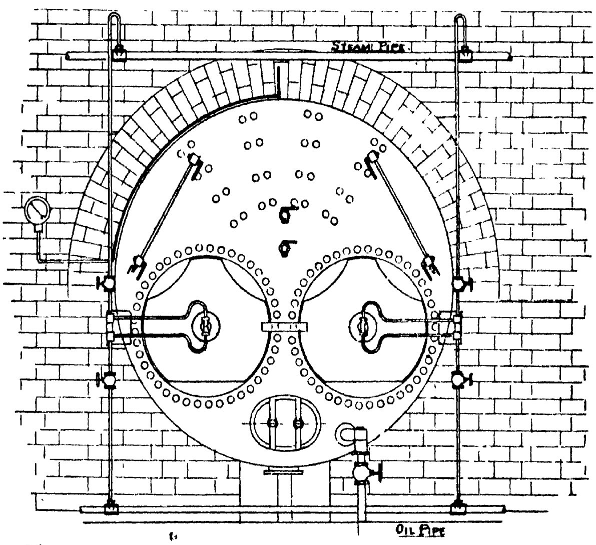


Fig. 131.—Arrangement of Lancashire Boiler for Liquid Fuel with Steam Burners.

allows the burner to throw a horizontal jet in the centre of the flue. Air regulation facilities are provided, and the burners are hinged to swing them aside when access to the flues is required. Sometimes the first few feet of the flue are lined with fire-brick, and some engineers prefer a perforated fire-brick baffle against which the flame may impinge before passage along the flue.

For the satisfactory combustion of oil large furnace space is necessary, at least $\frac{1}{10}$ cub. ft. per lb. of oil burnt per hour. Air admission should be regulated on furnace fronts, and at least

6 sq. in. of air opening should be allowed per gallon of oil burnt per hour. An inspection hole should be provided to watch the flame whilst effecting adjustment to secure a bright clear flame.

Fuel tanks are generally raised to give a gravity fall to the burners, and they are usually provided with a steam coil to accelerate deposition of water and dirt, and secure fluidity in cold weather when crude is used on the field. In all cases a draw-off pipe for deposited water and mud is fitted to the fuel tank.

Theory of Oil Combustion.—Crude oil, for the purpose of considering its thermal value, may be assumed to have the approximate composition of 86 per cent. of carbon and 14 per cent. of hydrogen by weight. Certain combined impurities such as sulphur, nitrogen, and oxygen occur in some oils, but their percentage is usually low. Complete combustion causes the dissociation of the liquid hydrocarbons with final formation of stable oxidation products in the form of carbon dioxide and water, the latter appearing as steam in the products of combustion. Imperfect oxidation yields carbon monoxide, as in coal, also much free finely-divided carbon particles that produce an exceedingly dense smoke.

The chemical reactions are:—

$$C + 2(2N_2 + O) = CO_2 + 4N_2.$$
$$H_2 + (2N_2 + O) = H_2O + 2N_2.$$

1 lb. carbon requires 2.66 lbs. of oxygen or 11.4 lbs. of air to form 3.66 lbs. of CO_2.
1 lb. hydrogen „ 8.00 „ „ 34.4 „ „ 9.00 „ H_2O.

An oil containing 86 per cent. of C and 14 per cent. of H would therefore give—

$$\begin{array}{llll} .86 \times 2.66 = & 2.29 \text{ lbs. of O} & \text{producing} & 3.15 \text{ lbs. of } CO_2. \\ .14 \times 8 = & 1.12 \text{ lbs. of O} & ,, & 1.26 \text{ lbs. of } H_2O. \\ \hline 1.00 \text{ lb.} & 3.41 \text{ lbs. of O} & ,, & 4.41 \text{ lbs. of gases.} \end{array}$$

As air contains 23.15 per cent. by weight of oxygen, the amount of air needed to chemically combine and complete the combustion of 1 lb. of petroleum is—

$$\frac{3.41}{.2315} = 14.75 \text{ lbs., or } 14.75 \times 13.4 = 194 \text{ cub. ft.}$$

at normal temperature and pressure.

With a 50 per cent. excess of air and a steam burner using

1 lb. of steam per lb. of oil, the following quantities of gaseous products would be formed:—

CO_2 - - - - - - - - -	3.15 lbs.
H_2O {1.26 lbs. for combustion of oil / 1.00 lb. used by burner} - - - -	2.26 ,,
N (14.75 lbs. air, less 3.41 lbs. of O used in combustion)	11.34 ,,
Air (50 per cent. excess) - - - - -	7.38 ,,
Total flue gases - - - - -	24.13 lbs.

There is in the above mixture—

$$\frac{3.15}{24.13} \times 100 = 12.6 \text{ per cent. of } CO_2.$$

$$\frac{2.26}{24.13} \times 100 = 9.36 \quad ,, \quad ,, \quad H_2O.$$

The complete oxidation of 1 lb. of C to CO_2 results in evolution of 14,650 B.T.U.
,, ,, ,, H to H_2O ,, ,, ,, 62,100 ,,

Therefore—

0.86 × 14,650 =	12,600 B.T.U. are liberated by combustion of	carbon.
0.14 × 62,100 =	8,694 ,, ,, ,, ,,	hydrogen.
	21,294 ,, ,, ,, ,,	1 lb. of petroleum.

The calorific value of 1 lb. of crude petroleum of the above composition is, therefore, 21,294 B.T.U., and the evaporative power

$$\frac{21,294}{966} = 22 \text{ lbs. of water from and at } 212^{\circ} \text{ F.}$$

In practice the water passes through the flues as steam, so that the heating value of the oil must be reduced by the latent heat of steam, that is—

.14 × 9 lbs. × 966 = 1,217 B.T.U., or 5.7 per cent., reducing heat value to 20,077 B.T.U. per lb.

Again, products of combustion and excess of air carry away to the atmosphere, in practice, the following amount of heat for each 1° F. of temperature, neglecting slight corrections for temperature:—

		Specific Heat.	
Carbon dioxide	- 3.15 lbs. ×	.216 =	.680 B.T.U. per 1° F.
Steam -	- 2.26 lbs. ×	.479 =	1.083 ,, ,,
Nitrogen -	- 11.34 lbs. ×	.244 =	2.765 ,, ,,
Air - -	- 7.38 lbs. ×	.238 =	1.765 ,, ,,
Total carried away in gases		-	6.293 ,, ,,

If flue gases have an escaping temperature of 600° F., the heat carried away and lost with air temperature of 60° F. is $(600^\circ - 60^\circ) \times 6.293 = 3{,}400$ B.T.U. per lb. of fuel burnt, approximately 17 per cent. of the heat value of an oil of 20,000 B.T.U. In one case the author recorded a flue temperature at base of chimney of 815° F. when the loss was $\frac{(815^\circ - 60^\circ) \times 6.293}{20{,}000} = 23.7$ per cent., about 10 per cent. higher than was necessary with economical running.

Petroleum fuel of 20,000 B.T.U. calorific value, devoid of all impurities, should give in a Lancashire boiler with a flue temperature of 450° F. an evaporation of about 16.25 lbs. of water from and at 212° F., equivalent to a conversion of 78.5 per cent. of the heat value of the fuel.

Flame temperature of the combustion of carbon and hydrogen is as under:—

	In Air.	In Oxygen.
C to CO_2	4,988° F.	18,440° F.
H to H_2O	4,554° F.	12,202° F.

Water contamination has a very serious influence on the calorific value of oil. Orde[1] and Vivian Lewis have written on this subject. Five per cent. of water reduces the calorific value by about the equivalent of an evaporation of 1 lb. of water, or between 6 and 7 per cent. A simple way of estimating the calorific value in B.T.U.'s of an oil from an analysis is

$$\text{B.T.U.'s} = 14{,}500\ C + 62{,}100 \left(H - \frac{\text{Oxygen}}{8}\right).$$

Feed-Water Heaters.—Where batteries of boilers are erected, it is now customary to introduce feed-water heaters (economisers), superheaters, and other devices to save fuel, especially where salt water is in use with its accompanying serious waste of fuel. When fresh water is fed to boilers, the feed-water heaters can be placed in the flues, but when the feed is salt water, or other very hard and untreated water, exhaust steam only should be used, or a deposit of lime or other salts will form and choke the feed heater. By

[1] Paper on "Liquid Fuels," *Inst. Mech. Eng.*, July 1902, by Mr Orde.

heating feed water from 60°-180°, a saving of over 10 per cent. in fuel can be obtained, besides reducing the strain imposed on a boiler by feeding with cold water. When no special feed-water heaters are available, it is a common plan to allow the feed water to fall in a spray through a vessel into which the exhaust steam pipe from the surface is led, the steam being thereby partially condensed, and the water raised in temperature. In such cases means should be taken to remove all grease or oil from the water.

Feed-water heaters need no description, as they are now made by nearly all firms interested in steam plants.

Superheaters.—Superheaters have been greatly simplified of late, and can now be purchased in units which permit of addition or abstraction of sections as occasion warrants. The steam from the boiler is led through a series of tubes exposed to the flue gases before it enters the main steam pipe, the temperature thereby being raised some 400°-500° F. above that due to the steam pressure. The saving resulting from the introduction of superheaters where there are long mains is considerable, as practically dry steam can be conveyed long distances. The superheat is rapidly lost unless the steam mains are well lagged with insulating material, which latter must not be of a combustible nature.

Condensers.—The greater attention to fuel economy has led operators in many districts, where salt water is used for the generation of steam, to take measures to recover their exhaust steam for partially replacing the inferior salt water. Where there is a large supply of bad quality water, this plan can often be introduced with considerable success. Salt water causes losses in a variety of ways. There is often a 30 per cent. blow-off to keep the salinity down to workable limits of safety, periodical stoppages for cleaning, and great evaporation losses through the formation of scale on the furnace tubes and boiler shell. The total loss of fuel as a result of using water of ocean salinity cannot be less than 20 per cent. under good working conditions, and producers are now taking measures for the condensation and use of exhaust steam.

The subject has been simplified by the manufacture of compact, light condensers of great efficiency and suitability for oil-field work by the Liverpool Engineering and Condenser Company under

Quiggin's patent. An inexpensive Quiggin's condenser, suitable for condensing 10,000 lbs. of steam per hour, only weighs 30 cwt., and will condense 40 lbs. of steam per square foot of cooling surface at atmospheric pressure with a consumption of only 15 lbs. of cooling water per lb. of steam. By coupling up an exhaust main to a number of steam engines, pumps, or other steam-using contrivances, the whole may be condensed and returned as feed to the boilers after treatment for the extraction of grease.

Inexpensive grease extractors of standard design can be purchased in the market, but efficient substitutes can be made by passing the steam through vessels containing steel turnings on trays. The oil clings to the metal and eventually collects at the base of the apparatus, from whence it can be withdrawn.

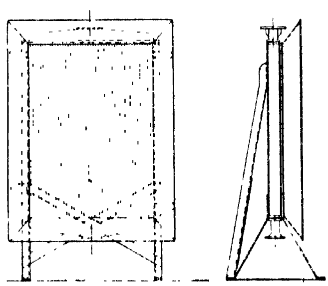


Fig. 132.—Aero-Condenser.

Where water of any kind is very scarce, aero-condensers are sometimes used. In 1898 a special portable type was designed for a district where there was little water available, and the climate was tropical. The steam was led into a radiator of special form, and air was impelled past the radiator by a fan running in ball-bearings fitted to the framework. The condenser weighed complete 168 lbs., and condensed 480 lbs. of steam per hour, with an expenditure of 1.5 H.P. on the fan. The results of a trial were as follows:—

Revolutions of fan per minute	880
Power for driving	1.5 H.P.
Temperature of air at inlet	96.8° F.
Temperature of air at outlet	159.8° F.
Temperature of condensed water	203° F.
Water condensed per hour	480 lbs.

It was later found possible to dispense with the fan entirely and utilise the prevailing wind without great loss of efficiency.

Evaporative condensers are often erected in places where there is only a limited supply of fresh water. Exhaust steam is led through a series of tubes—usually built up in units—on the outside of which a steady stream of water is allowed to trickle. The rapid evaporation of the water coming into contact with the hot tubes causes condensation of the steam. By using evaporative condensers 100 lbs. of steam can be condensed with a loss of two-thirds of 100 = 66 lbs. of water. If impure or salt water is used for evaporative condensers, a deposit accumulates on the tubing, impairing the efficiency, and making it necessary to take measures to secure its removal.

All surface condensers require a considerable quantity of circulation water, and if there is a scarcity, or it has to be pumped some distance or height from its source to the condensers, it is good practice to erect cooling towers. Cooling towers can be cheaply constructed of timber, the hot water leaving the condensers being pumped to a chute from which it trickles down over a number of baffles through which air circulates. The evaporation of a small proportion of the water causes the rapid cooling of the remainder to the temperature of the air, so that it can be used over and over again, the loss alone being made good by added water. If the loss during the operation from all sources is 10 per cent., only 10 per cent. of the quantity of circulating water is needed after the first supply has been pumped up. In tropical climates the loss through evaporation may exceed 10 per cent., but in temperate climates the loss will rarely exceed that amount.

Evaporators.—The preparation of distilled water from impure water was at one time an expensive operation, as 1 gal. of pure water only could be obtained from the direct evaporation of 1 gal. of impure water, the latent heat of the steam being imparted entirely to the circulating water of the condenser and wasted. Modern distilling plants are multiple in effect; that is, the latent heat of the steam is utilised in evaporating other water at a reduced pressure, and the new steam generated is again employed for evaporating still more water at a further diminished pressure.

There are many such evaporators in the market now, from

which, by multiplying the effect, the following results can be obtained from the evaporation of each gallon of water :—

Single effect	- 1.8	gals. of water per gallon of water directly evaporated.
Double effect	- 2.4	" " " "
Treble effect	- 2.9	" " " "
Quadruple effect	- 3.3	" " " "

From the above it will be seen that with an evaporation of 14 lbs. of water per lb. of oil fuel, 1 lb. of oil will produce 46 gals. of water in a quadruple effect plant.

The last evaporator units are worked under a high vacuum to reduce the temperature of evaporation, and the dense impure water which passes in succession through each unit is drawn off the last evaporator by a brine pump. The feed-water pump and air pump exhaust into the condenser, and the evaporators are made in such a way that the deposited salts can be easily dislodged from the tubes and cleaned out at intervals.

A triple effect evaporator plant producing 350 tons of fresh water daily from sea water on an oil-field was run at the cost below :—

Running and maintenance	$0.113	per ton	
Repairs and renewals	0.056	"	
Depreciation	0.050	"	
Administration, etc.	0.057	"	
Fuel (gas at 10 cents per 1,000 cub. ft.)	0.005	"	
Total cost	$0.281	"	= 1s. 2d.

Steam Mains.—The following hints on the construction of steam lines may prove helpful to those unacquainted with oil-field conditions. All pipes should be kept above ground for observation, but if laid beneath the ground level they must be well insulated and surrounded by cinders or other porous material to allow water to drain away. To avoid impeding movements of persons and goods on the property steam mains are usually carried overhead on standards at sufficient height for objects to pass beneath. These standards are frequently constructed from discarded casing or eroded piping, to which the steam pipes are attached by clips, or on which they rest in suitable crown brackets. Wooden standards should be avoided owing to the damage they sustain in a fire, and the danger from rot, especially in the tropics.

Steam pipes should be well insulated by some heat non-conducting medium. In this connection it is well to recall the fact that all insulating materials owe their efficacy to air, which is a very bad conductor of heat, retained in innumerable interstices throughout their mass. Clay, earth, and such materials have poor insulating properties, although often used on oil-fields in a laudable but mistaken effort to economise. It usually pays to purchase some of the recognised goods in the market, such as hair felt, asbestos, or cellular asbestos. These substances are too expensive to neglect, and it is customary to protect them, after attachment, with some more substantial covering, such as sheet iron or canvas.

Means must be provided to allow for expansion and contraction, otherwise leaky joints will be a constant source of annoyance. Large U's or hoop loops are usually preferred to those with a packed gland owing to simplicity; and at the same time such fittings are used for the drainage and removal of condensed water. Without such provision for extraction of water, steam traps are necessary at intervals in long circuits.

The author has for some years largely employed short lengths of flexible metallic hose for coupling up machinery to pipe lines. The mass of fittings that are used by unskilled labour when connecting up a main to some plant is often amazing; and besides the expense, time of erection, and increased number of joints to leak, there is the serious resistance they impose to the flow of steam. No oil property should be without these lengths of assorted flexible piping, as besides saving hours of toil and considerable expense, they constitute effective expansion joints and shock absorbers. No matter how much vibration there is on the engine, little is transmitted to the mains, such as one so frequently sees where engines are run too quickly on rough foundations. Lengths of from 3-8 ft. are usually sufficient for most purposes. The smaller sizes up to 2 in. may, with advantage, be supplied with union connectors, but larger sizes should have flanged connections. Copper or gun-metal should be used to avoid the corrosion that in time destroys steel tubing even when galvanised.

Steam Engines.—Steam is still the main source of power on oil-fields, and the steam engines in use for various purposes,

mostly of a temporary nature, are of the non-condensing type, free from all refinements that would imperil their safety in the hands of unskilled oil-field attendants to whom machinery is largely entrusted. In those fields where other and more convenient, or more economical, sources of energy have been introduced, operators have often hesitated to scrap the large quantities of plant in hand for which no ready market is found.

Drillers almost exclusively prefer a steam engine owing to its wide latitude in power, flexibility in speed, and the way in which it withstands the roughest usage, that no amount of supervision will prevent. Governors are never entertained, and promptly put out of action if fitted to drilling engines, thus enabling the engine to be run at a speed that would alarm as well as surprise the manufacturers themselves. Cable drilling is mainly performed by single-cylinder, horizontal, reversing engines varying from 8 in. × 12 in. to 12 in. × 14 in., weighing from 1-2 tons. The smaller engines are for shallow drilling, the large for deep wells of 2,500-3,500 ft., and often of considerable initial diameters. The main features distinguishing a drilling engine are (*a*) the attachment of an equilibrium valve at the steam admission, or a valve with rope pulley that can be actuated from a distance; (*b*) levers enabling the reversing gear to be operated from the rig by a rope or rod; (*c*) great strength and absence of finish; (*d*) detachable fly-wheel rims. Sometimes a feed pump and exhaust steam feed-water heater are attached to the engine.

Sensitivity is the chief object to be attained in cable drilling, and it is the ready response of the steam engine to the influence of variable resistances that appeals to drillers. During the descending stroke of cable tools the engine races and permits a harder blow being delivered, and on the ascending stroke the engine slows up, thus diminishing the strain on the cable and rig. Flexibility is assisted by the use of a fly-wheel with detachable rims that can be added to or be removed to suit the depth of well, weight of tools, and speed of running.

Large diameter wells, sunk in some of the Roumanian and Russian oil-fields, call for engines of much greater power, and double cylinder 12 in. × 16 in. stroke are frequent, especially where low pressure steam (60 lbs.) is used, and long transmission lines often

further reduce the available pressure. Working boiler pressures of from 60-150 lbs. per square inch are usual on oil-fields.

Non-compounded, non-condensing, low pressure steam engines are very uneconomical in practice. A consumption of from 40-50 lbs. of steam per B.H.P.-hour is usual, and this quantity may be far exceeded where condensation is great in long badly-insulated mains. The thermal efficiency of a high class steam engine, with all modern refinements, may be as high as 18 per cent. Thus the potential energy in 1 lb. of steam at 160 lbs. pressure from water at 62° F. will generate 0.45 H.P.-hours. A consumption of 12 lbs. of steam per B.H.P.-hour, representing about the best results attained in practice, is equivalent to $\frac{1}{12}$ B.H.P. per lb. of steam, therefore the thermal efficiency is $\frac{\frac{1}{12}}{.45}$ and $\frac{.083}{.45}$ of $100 = 18$ per cent.

In oil-field practice, where 50 lbs. of steam are used per B.H.P.-hour, the thermal efficiency would be $\frac{\frac{1}{50}}{.45}$ and $\frac{.02}{.45}$ of $100 = 4.2$ per cent. only. The mechanical efficiency, *i.e.*, the ratio of Brake to Indicated H.P., will vary between 70 and 94 per cent. according to the class and size of engine.

Internal Combustion Engines.—The use of internal combustion engines for oil-field duties is continually extending, and there remain few duties to which they cannot be economically or efficiently adapted. Reversing facilities yet only partially overcome have been an obstacle to their employment for certain forms of drilling, and operations demanding reverse movements, and the difficulty of varying speeds and overloading, have somewhat restricted their adoption. Clutches and gear boxes have been designed to effect the above requirements, and there is little doubt that suitably arranged devices will be forthcoming for dealing with the problem, as in the case of automobiles.

Several other factors have acted as a deterrent to the general use of larger engines, but especially the need for substantial foundations to resist the shock inseparable from such engines. The heavy fly-wheels are likewise a cause of expense and trouble in conveyance over difficult country, and the somewhat more complicated working parts are a constant source of anxiety to operators without engineering knowledge. Repairs, too, are less

easily effected than in steam engines in outlying districts and foreign countries where few or no workshops exist.

For works of a permanent nature the above objections apply less forcibly, and the cost of foundations, building for housing, and provision for repairs is justified by the great fuel saving eventually effected.

One objection to the general adoption of internal combustion engines for oil-field operations is the decentralisation of plant involved, centralisation being one of the aims of all engineers. Waste of energy cannot be avoided in groups of isolated units, where each motor must be designed to supply the maximum power demand and this latter may only be called upon for a few hours daily. Efforts have been made to minimise this objection by using one single large unit for several duties, as a multiplicity of foundations, housings, and attendants is always a source of expense. These objections have also been partially overcome in some cases by the installation of power stations where energy in the form of electricity, compressed air, or wire line transmission could be arranged. The great saving in fuel neutralises many objections, and even allows units of large power to replace steam, which has long held the day. The table below gives the comparative figures of steam and internal combustion engines of about 30 H.P.

Power.	Fuel (per B.H.P. Hour).	Thermal Efficiency.	Approximate Cost per H.P.	
			£	$
Steam engine and boiler	4 lbs.	3.5 per cent.	8-10	42.5
Gas engine (natural gas)	15 cub. ft.	16.0 „	7-10	37.5
Oil engine (crude)	0.75 lb.	18.0 „	10-5	51.2

Oil Engines.—The use of oil engines for oil-field operations is steadily advancing, and where difficulties practically preclude the possibility of employing steam, they can be used with some forms of drill, and have many times been put to practical use in drilling wells. For steady work, such as pumping or bailing wells, generating electric light, pumping water or oil about the field, and driving other subsidiary plant, oil engines can be employed with considerable economy over steam.

The purchase and installation of an oil engine entails a

somewhat higher cost than that of a steam installation, but, on the other hand, there is a much less margin of reserve power in the former than the latter. For powers exceeding 50 H.P., oil engines become bulky, and some difficulty is often experienced in starting them; indeed, it is always advisable to have a small oil engine, or some other power, for putting them in motion.

For oil-field duties the crude oil engine is favoured, and the common necessity for heating up the vaporiser to a high temperature—as is usual in this type of engine—by a lamp, which would be accompanied by too much danger in some situations, is overcome by starting the engine cold on benzine, and continuing until the vaporiser reaches the requisite temperature to run on crude. Crude oil taken direct from the well should be allowed to stand a while for the separation of water and sand before it is led to the engine. The high compression engines now being made can be started cold, and have all heated parts totally jacketed. They are also designed to run on gas by the attachment of certain fixtures that can be quickly connected.

Where the local waters are excessively charged with lime salts or common salt, condensed water should be used, and the loss by evaporation periodically made up. The author's attention has several times been directed to accidents which have originated through the cooling chambers and circulation pipe becoming furred up with salts of sodium and lime, with consequent overheating of the cylinders. In tropical climates the capacity of the circulation water tanks should be considerably increased, and special provision should be made for automatically recording the level of water, the fall of which would cause the circulation to cease.

A crude oil engine consumes from ¾-1 lb. of oil per horse power per hour compared with 3-6 lbs. for a steam engine under usual oil-field conditions, but more skilled attention is required, and the expenditure on repairs is higher in the case of all internal combustion engines.

The Diesel oil engine is even more economical, and will consume practically any kind of liquid combustible, but for oil-field conditions it is somewhat expensive, and requires more attention than the ordinary low pressure variety. For permanent installations in well-sheltered buildings, under the immediate

supervision of a qualified attendant, the Diesel engine is particularly applicable and exceptionally economical in fuel.

The theoretical energy of 1 lb. of oil of 18,000 B.T.U.'s would generate about 7 H.P.-hours, consequently an oil engine consuming 0.75 lb. of oil per H.P.-hour, or, in other words, in which 1 lb. of oil generates 1.33 H.P., would have a thermal efficiency of $\frac{1.33}{7} \times 100 = 19$ per cent. The mechanical efficiency of oil engines may vary between 75 and 85 per cent., according to size, design, etc. With a consumption of only 0.5 lb. of oil per B.H.P.-hour, the thermal efficiency of oil engines rises to 28 per cent., but this latter is only possible in high compression engines working under favourable conditions.

Gas Engines.—In the American oil-fields, gas engines have always been largely employed for power purposes other than for drilling, in consequence of the majority of wells in that country being pumped, thus permitting the simple provision of leading away the gas from the well by a side outlet pipe without any intermediary plant. In many of the eastern oil-fields of the United States, wells are specially sunk for gas which escapes under high pressure, and is either led direct or pumped to centres of commercial activity. Natural gas has a calorific value approaching 1,000 B.T.U. per cubic foot, compared with 500-700 B.T.U. for artificial coal gas, but in practice the consumption per horse power is about the same as coal gas, 9-15 cub. ft. per horse power per hour according to the size of engines, etc. As natural gas usually contains moisture in suspension, and the pressure when the gas is led direct from the well often fluctuates, it is advisable to introduce a small gasometer for the equalisation of pressure and the separation of water when gas engines are fed direct from oil or gas wells.

Gas engines are often operated by allowing the engine to draw its supply of gas direct from the well, the suction pipe being led into the well sufficiently below the surface to avoid the introduction of air during fluctuations of gas supply. If the engines are far removed from the wells from which they obtain their supplies, and there is either insufficient pressure to overcome the friction of pipes, or the wells are open to the

atmosphere, as in the case of bailing or drilling wells, the gas may be extracted and forced to a distance by a small compressor, or, in the case of large volumes, by a fan or blower.

Most gas engines can be adjusted to utilise natural gas, although its variable composition and the fluctuating proportion of moisture introduce factors of uncertainty which sometimes cause erratic working for a time. Where the engines exceed 30 H.P. supplementary power should be provided for starting, as there is often far more trouble in starting than with an engine using gas of constant quality.

Simplicity in oil-fields takes precedence of economy in gas consumption, which latter is usually unworthy of consideration when thousands of cubic feet daily go to waste from nearly every well. The Bessemer gas engine illustrates a type especially commendable, the whole working being effected by the operation of a single valve. Speed can be adjusted by regulation of gas and air supply; the engine will run equally well in either direction, and almost any grade of gas can be used. By an ingenious design of piston the inflowing combustible mixture of gas and air is used to scour the cylinder of the products of the preceding combustion, ports in the cylinder wall being closed at the right moment to enclose the new charge for compression prior to ignition. Air and gas are drawn through small orifices in the same inlet valve, thereby causing intimate admixture, into the crank end of the cylinder during the back travel of the piston following an explosion on the return forward stroke. The enclosed mixture is compressed, and at a certain point ports open admitting this mixture to the front of the piston, thus driving out the contained products and itself being further compressed and ignited at the end of the stroke on the closing of the exhaust port. The piston thereby gets a propulsion at every revolution and needs no adjustment but the gas and air admission that is operated by the governor.

In new oil-fields, where high gas pressures are met with in the wells, gas is sometimes led direct to steam engines, and the engines run on gas instead of steam. The cooling effect of the expanding gas causes the condensation and freezing of

moisture on the engine until often the machine becomes coated with a thick deposit of ice.

Much ingenuity has been expended in the construction of a convertible steam engine, whereby at any moment the steam cylinder can be replaced by a gas cylinder, thereby creating a gas engine. Such engines have proved satisfactory in practice, although they naturally lack some of the qualities that attach to an engine designed for the single purpose.

Electric Lighting.—The use of electricity for illuminating purposes on oil-fields is almost universal, even small prospectors in new fields deeming it wise to install a diminutive plant of 1 or 2 kw. capacity if night work is undertaken. This attitude arises from the grave risk of fire attendant upon the use of naked lights, and the uselessness of the glimmer afforded by miners' lamps.

Both petrol engines and steam turbine-driven dynamos are used for these installations, the latter being perhaps the more convenient and cheap to install where steam power is employed for operating the rig. The voltage adopted for lighting purposes is usually 110. The lamps should always be mounted in heavy water and gas tight fittings in which the glass globes are protected from injury by stout wire screens. Metallic filament lamps of the traction type can safely be installed if care is taken to select positions where vibration is not too pronounced.

The wiring in rigs may be run on cleat insulators if the boring is not likely to be very prolonged, and the well is being drilled in ground not productive of spouting wells, otherwise all wires should always be carried in screwed metal tubing with which the lamp fittings should be solidly connected. The wire should be of first-rate quality of not lower than 600 meg. grade, the insulation being of vulcanised india-rubber, taped, braided, and waterproofed. The entire circuit of each rig should be controlled by a double pole switch, and fuses should be placed outside the rig at the end furthest from the well, by which means current can be instantly cut off from all the lamps should violent spouting of the well or other reason make this imperative.

The flexible connectors of portable hand lamps used in the derrick should be of the heaviest pattern obtainable, thickly padded, waterproofed, and protected outside by strong braiding;

the plugs for such lamps should always be lightly fused in view of the possibility of the wire being cut by casing, or some heavy tool being dropped upon it.

Where electricity is used on larg fields for lighting only, the current will usually be generated in a central station in which the motive power is furnished by gas or oil engines. Distribution is best effected by means of bare wire overhead conductors carried on wooden or iron poles, fitted with cheap glass or porcelain petticoat insulators. To minimise waste in transmission of the current, the voltage of such installations should preferably be as high as possible, say 1,000 volts, for alternating current, with a small transformer reducing it to 110 volts at each well; and 220 volts in the case of direct current. The size of wires used should be chosen so that the current to be carried does not exceed 1,000 amperes per square inch. The conductors of a bare wire overhead transmission should in no case be less than No. 7 S.W.G. Although the transmission line may be cheaper in the case of the high voltage alternating current, the advantage in this direction will be offset to a great extent by the cost of providing a small transformer and switchgear at each well. A feature of such equipment should be an oil switch in the primary leads to the transformer, so that current can be switched off it when not in use, thus saving the otherwise considerable standby losses.

Direct current lighting dynamos should be level compound wound, so that the voltage at the terminals is the same for all loads, and unless they are to be installed in a carefully designed building with a perfectly sound roof, they should be constructed drip proof; the usual protected type of machine, with sheet iron taking the place of the gauze on the upper half of the commutator and back end screens, will fulfil this requirement without being expensive.

Electric Power.—The old prejudice against electrical energy on oil-fields is rapidly disappearing in view of the very great strides which have been made in the application of electricity to power purposes. So much experience has been gained of late years in the application of electrical power to traction, rolling mill, lift, and other such purposes requiring widely and suddenly varying speeds and power that the necessary equipment of motor and controlling gear suitable for oil-field purposes can be selected

from standard types. Much good work has been done in the electrical equipment of the American oil-fields and also in the Baku oil-fields of Russia and in Roumania.

Early efforts to apply electrical power met with indifferent success largely on account of failure to appreciate the extent of the "peak" loads in electrical transmission to oil-fields, and to the initial difficulty of giving effect to variable speeds. Power is furnished to the oil-fields of Baku by two generating stations of a collective capacity of 16,500 H.P. A station at Whitetown supplies power to the Balakhany-Saboontchy-Romany-Surakhany area, and another at Baieloff generates power for the Bibi-Eibat oil-field. Three-phase alternators are installed at Whitetown with a tension of 6,000 volts, part of which is transformed up to 20,000 volts for transmission to the outskirts of the oil-field. For distribution a voltage of 1,000 is employed, whilst at Bibi-Eibat the full generating pressure of 2,000 volts is supplied direct to the motors.

Roumanian oil-fields are fed by two generating stations, one at Sinaia where Francis water-propelled turbines are utilised to drive three-phase alternators of 3,000 volts, transformed to 11,000 volts for transmission over a distance of 35 km., and another at Campina where steam is the source of power.

Power Requirements—Drilling.—The power used at a well varies very widely with the nature of the work to be performed. During the drilling of a well several separate, distinct operations are involved, comprising the actual manipulation of the tools, bailing the detritus in the case of percussion drilling, or pumping the flush water under the rotary and other flush systems, manipulating casing, and trial bailing. The first of these requires the least power, and will rarely call for more than 25-30 H.P., but the work of hoisting the tools, removing detritus, and manipulating casing is much heavier, and takes quite twice as much power, and the speed required is also much higher. These considerations make it necessary to install a motor with a large range of speed and power. In arranging a drilling rig for electric drive the usual type of transmission is required, but the fact must not be overlooked that the motor speed will be very much higher than that of the normal drilling engine, and the proportions of pulleys will therefore have to be arranged accordingly. The higher the

speed the cheaper the first cost of the motor will be. The usual speeds adopted are from 900 up to 1,200 revs. per min. For the highest speeds belt or rope drive should always be adopted as back-geared motors are too noisy. A motor of liberal capacity should be provided, and never less than 50 B.H.P. at top or synchronous speed for normal wells of shallow or medium depth, and 75 B.H.P. for wells of about 2,000 ft. and upwards. The power at lowest speed should not be less than 25 B.H.P., and the motor and control gear should be capable of sustaining 33 per cent. to 50 per cent. overload at all speeds for half an hour.

The bailing referred to above is trial bailing only, and would be carried out with comparatively small bailers at speeds not exceeding say 300 ft. per min. It must not be confused with heavy production bailing such as pertains in the Russian and Roumanian oil-fields where large bailers 50 ft. and more in length are operated at 800-1,200 ft. per minute; such bailing requires motors of 200 H.P. and more. It is sometimes unnecessary to bail a well continuously through the twenty-four hours, and this fact is often taken advantage of by arranging a motor in such a position that two wells can be operated by it alternately, thus effecting a substantial saving in the cost of equipment.

Pumping.—Wells may be pumped either individually or in groups, the method adopted depending upon the proximity of wells and other factors, such as the distribution of well sites and their accessibility. It is customary in many fields to pump wells from the beam in the first instance, while the production is large and while it is necessary to keep the rig *in situ* for frequent cleaning, such wells being afterwards connected up to the central power when they have settled down to steady conditions.

In cases where pumping from the beam is of a temporary nature as indicated above, the drilling motor should be left in the rig to do the work, but where it is intended to pump the well from the beam permanently, a similar variable speed motor rated at 24 H.P. when running at highest speed and giving 8 H.P. at the low pumping speed can be installed in place of the drilling motor. Such a machine will be able to operate the pump at any desired speed, and also to furnish power for occasional cleaning operations, and for the necessary manipula-

tion of the pump rods and tubing. In the case of large producers, or wells operating at great depth, or where much fine sand is encountered, greater power will be required, and a motor rated at 45/15 H.P. should be installed. It is necessary to provide a motor sufficiently powerful to raise the pump rods and tubing and clean the well, but it is not good practice, as is sometimes advocated, to install a machine capable of handling casing, even under overload conditions. A motor of this kind would be uneconomical when doing its normal pumping work, and the first cost would be unduly high. A far better policy is to reinstate a drilling motor in the event of redrilling or manipulation of heavy casing being decided upon.

Groups of wells can be best pumped from a central pumping power by constant speed motors, although even for this work, if the power is furnished by direct current, the motor could with advantage be arranged for speed variation of 10-15 per cent. The power required will vary from about 1-2¼ B.H.P. per well connected, the lower value being taken for large groups of 20-25 wells on one power, and the higher figure where there are only 5-10 wells. Thus for a large pumping power operating 25 wells, a motor of 25 B.H.P. capacity will suffice where the conditions are favourable. The above method of group pumping, by which a large number of wells can be linked up and balanced one against the other and arranged so as to perform their power stroke in sequence, leads to great economy both in capital outlay and running costs. Pumping powers should always be fitted with fast and loose pulleys or a clutch, so that the motor can be gradually speeded up under light load, thus enabling a motor and switchgear of very simple type to be utilised.

Type of Plant.—Either direct or polyphase current is suitable for oil-field work, but in view of the greater efficiency of direct current variable speed motors, the former is to be preferred. Large consumers can make arrangements for distribution on this system, either by installing a power generating plant of their own, or by providing converters to transform polyphase current bought from a public supply company, by whom power is usually distributed in three-phase form at high tension. Small operators, who seldom have in use a sufficient number of motors to make it worth while

either to install their own generating plant, or to convert the power purchased from suppliers, must use polyphase current motors.

Although less economical in use under the very variable conditions pertaining to oil-field requirements, these have been found to be both practicable and satisfactory. Whether the power be in polyphase or direct current form, the pressure at the motor terminals should be from 500-1,000 volts, and the periodicity of polyphase current, where there is a possibility of choice, should be 25 cycles per second, this value being chosen as more satisfactory than a higher periodicity for power purposes, and yet high enough to enable the rig lighting to be taken from the same circuit as the power.

Direct Current Working.—The economy of operation and the facility with which the speed of the direct current motor can be varied and the motor reversed, coupled with its ability to exert great torque or pull at starting and on low speeds, render this form of motor well adapted to the work of drilling wells and subsequently operating them for production. For driving multiple pumping powers the ordinary shunt wound motor is quite satisfactory provided that arrangements are made for starting it up free of load. Drilling, bailing, well cleaning, and casing operations require a motor capable of starting rapidly with a heavy load, and compound wound motors should always be chosen for these purposes, owing to their ability to exert a powerful torque or pull at starting, and rapidly accelerate up to full speed.

Compound wound motors meet the objections frequently urged against electric motors for percussion drilling. It has been claimed that the inertia of the heavy revolving mass of the rotor tends to keep it revolving at a uniform speed, which allows no give and take as the beam alternately picks up the tools and drops them, thus causing racking of the rig and checking of the downward fall of the tools. This objection would undoubtedly be justified if ordinary shunt wound machines were employed, but in the compounded machine the desired conditions are attained, the speed diminishing as weight is applied when the load of tools is taken on the beam, and increasing as the load is thrown off.

Percussion and rotary drills call for means of regulating the speed of running, the former by adjusting the oscillations of

the beam, the latter by varying the rate of the revolutions of the rotary table in a definite period. To secure proper speed regulation the shunt regulator must be finely adjustable, and the resistance is best arranged in two portions, main and secondary, the main resistance being in ten or twelve coarse steps, and the secondary in about an equal number of fine steps, the whole range of the secondary corresponding to one step of the main resistance into which it may be cut where requisite.

For successful working the motor control gear must be fool-proof. The main points to be considered in this connection are (*a*) the zero-volt and overload releases for opening the main switch should current fail or excessive overload occur; (*b*) the automatic insertion of the starting resistance and cutting out of the shunt resistance whenever the motor is stopped; (*c*) the automatic gradual cutting out of the former as the motor speeds up, and also auto-control of the manipulation of the shunt resistance for speed changing.

All the above requirements can be successfully met, and equipments embodying them are in everyday use. The object of such auto-control is to free attendants from the necessity of careful thinking before acting, and enabling them to start, and run, and change the speed of the motor with the same freedom with which they have been accustomed to when using the steam engine. The motor control gear should be placed in the position usually occupied by the ordinary steam control wheel, where it will be close to hand and convenient for the driller. All connections between the motor and control gear must be made with high quality india-rubber insulated cable enclosed in iron tubing, and should preferably be laid underground. Enclosure of the whole of the control gear in a locked hermetically sealed iron case, will contribute much to the convenience, safety, and satisfactory working of the plant. The door of this case should be so interlocked with isolating switches that current has to be cut off the switchgear before it is possible to gain access, or as a preferable alternative all resistances and contacts, switches, fuses, etc., may be of the oil-immersed type, all switches being arranged on the controller principle. Every equipment should be provided

with a voltmeter and a recording wattmeter. The value of the latter cannot be over-estimated, as it presents in the form of a chart a continuous record of the power used at a well, thus providing a most useful check on the operators, the value of which is specially accentuated in the case of night work. Several typical charts showing the record of power taken by various oil-field operations are shown.

The diagram (Fig. 133) will serve to indicate the essential features of the motor and controlling gear for diverse duties, the details of which are worked out in various ways by different designers and makers. The operating handles should be arranged in a simple and convenient manner, and each handle should be clearly labelled; the starting handle, "start and run" and "stop"; the speed regulator handle, "raise speed" and "lower speed"; and the reversing handle, "forward" and "reverse."

Polyphase Alternating Current Working.—It has been mentioned in a previous paragraph that electrical operation by polyphase alternating current is in general less economical than direct current working under oil-field conditions, but cases may occur where polyphase current is already available, and wells are so few or so widely spaced as to render its use, by means of polyphase motors, the more economical and workable scheme.

Where polyphase alternating working is adopted the power should be delivered to the well or group of wells at extra high pressure, *i.e.*, as received from the power lines, and should there be reduced to the pressure, about 500 or 1,000 volts, required at the motor terminals, by means of static transformers. These transformers should be placed on an elevated platform, which may be constructed high up on the posts carrying the power lines, and from them the low pressure wire should be brought to the derrick, either by means of overhead bare wires, or in a three core underground cable, according as to whether the distance be long or short. Where one well only is under consideration, an underground cable will probably be used as the extra high pressure line can be brought close up, but where arrangements are being made for a group of several wells, the transformers should be placed in a central position, the low pressure current

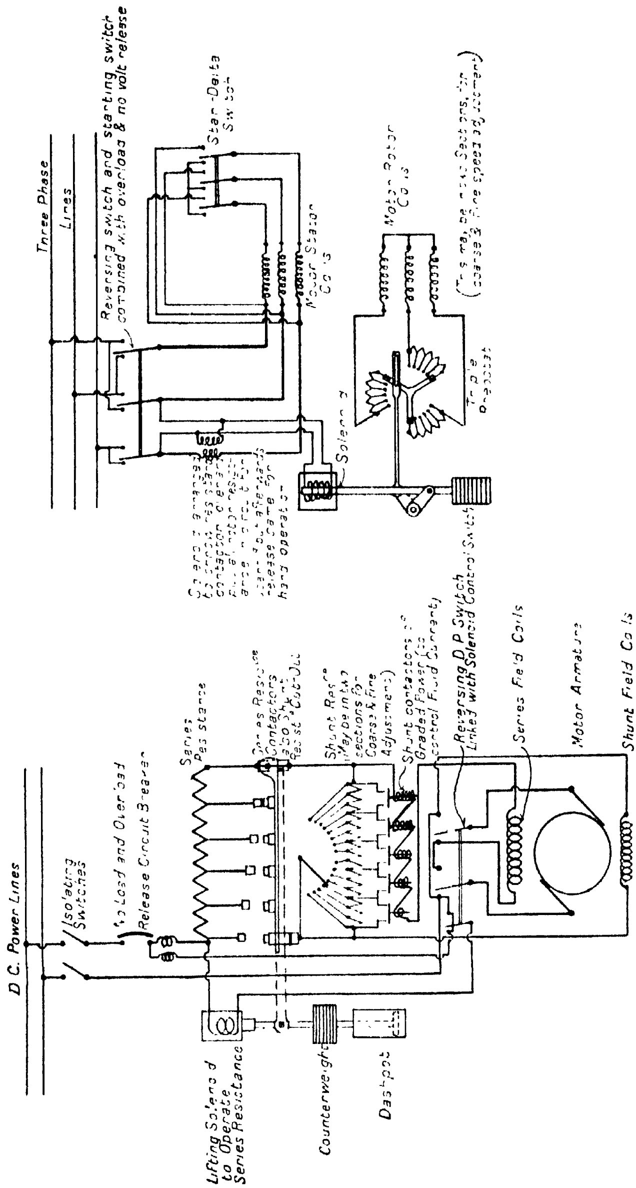


Fig. 133.—Diagram of Switchgear for Electric Drilling Motors.

being distributed by overhead bare wires. There is considerable advantage in grouping wells for this purpose, in that capital outlay and maintenance in transformers can be reduced, as they need only be of sufficient capacity to handle the average power required by the group, whereas in cases where a well has its own separate transformers, they must be of sufficient capacity to handle the maximum power demanded, and will generally be very much underloaded, and therefore running at low efficiency.

The conditions in every case will need close consideration, but, generally speaking, where a compact group of wells can be arranged to be at work fairly constantly, a central transformer station with low pressure distribution will give the most economical results. It would be in any case very objectionable to bring the extra high tension wires among closely spaced wells, and the transformer station should be located outside the dense area, due care being taken in arranging the distributing wires to guard against their being destroyed or interfered with, or in their turn obstructing the free working of the field.

Isolated or very widely spaced wells should each have a separate set of transformers placed near the well, the extra high tension supply current being brought right up to these. In all cases the extra high tension supply should, for safety's sake, never be brought to ground level, all transformers as before mentioned being located upon elevated platforms which should be unapproachable by any except duly authorised persons. On the platforms all extra high tension gear should be totally enclosed, and arrangements made so that access to any part cannot be obtained till the current has been cut off from same and it is laid dead.

The motors most suitable for drilling are two-speed machines with wound rotors. Such machines have two main speeds, both of which are adjustable, thus giving the required flexibility of speed and power, the lower speed and consequent lower power being used during drilling, and the higher speed and power for casing, tool withdrawing, and bailing operations. The necessary deviations from the normal speed on either high or low speed are obtained by inserting in the rotor circuit resistances operated from the control panel, but the change from higher to lower speed connections is made by means of a throw-over switch on the motor

case. As this large change of speed is required only at considerable intervals, when a change of operation in the rig takes place, this arrangement is found to be quite convenient. The rotor resistance should be of similar design to the shunt resistance described under "direct current working" in order to obtain close speed adjustment.

The diagram, Fig. 133, will serve to indicate the essential features of alternating current motor equipments for various oil-field purposes.

Cost of Electrical Power.—The cost of operating oil well machinery electrically naturally varies largely under diverse conditions, and according to figures published in *Western Engineering*, compares favourably with the cost of steam power where the price of current is reasonably low. The average cost of electric power per foot drilled for seven wells averaging 1,100 ft. deep is given as $.093 with power at $.015 per kw.-hour. In the power requirements for pumping wells there is more variation, depending upon the viscosity and gravity of the oil, the quantity being pumped, the size of pumps, etc. In group pumping the number of wells operated and their proximity to one another has an important bearing on the power required. Quoting again from the article mentioned above, the power consumed in group pumping shows a variation of from 18-40 kw.-hours per well per day, the lower figure being reached where 20-25 wells are operated from one power and the higher representing the consumption where there are a few only, say 6 or 8 wells; these figures correspond to a cost for power of 27 cents to 60 cents per well per day with power costing 1.5 cents per kw.-hour, and a cost per barrel of oil pumped of $.012 for an average production of 22 barrels per day to $.04 for an average of 15 barrels per day per well. In cases where wells are pumped individually from the beam the figures given are in the region of $1.00 to $1.375 per well per day, dependent upon the conditions.

It has been estimated that the average current consumed by wells in the Baku oil-fields of Russia was as follows:—

Boring wells, 8.5 kw.-hours (11.4 H.P.-hours) per hour, or 6,000 kw.-hours per month.

Bailing wells, 16 kw.-hours (21.5 H.P.-hours) per hour, or 11,500 kw.-hours per month.

The charge for electric power is there based on a sliding scale fluctuating with the prevailing average price of crude oil. With oil at 20 copecks per pood (26s. 4d. per ton = 85 cents per barrel) the cost of power in 1907 was 7 copecks (1.75 pence = 3.5 cents) per kw.-hour, or about £85 ($400) per bailing well, and £48 ($230) per boring well per month, and for each rise of 1 copeck per pood in the price of oil, the power rose .01 copeck per kw.-hour. In 1915 the price on large contracts for power was 6.25 copecks (1.56 pence = 3.1 cents) per kw.-hour, with oil at 40 copecks per pood (52s. 8d. per ton, $1.68 per barrel), a very great reduction on the old prices, and maintaining the average cost of power per well at about the same rate as those enumerated above, when power was 7 copecks per kw.-hour, with oil at 20 copecks per pood. This works out to 60 cents per ton (8 cents per barrel) of oil extracted from an average well yielding 20 tons (150 barrels) daily. When drilling at a rate of 180 ft. per month, the average cost of power is about 5.4 shillings ($1.29) per foot. Electrical power is supplied to the Kern River oil-field of California from a hydro-generating station in the mountains at 1.5-1.9 cents per kw.-hour.

The Russian Government allowed a rebate of 4 kg. of oil per kw.-hour on royalty oil, when purchased electric power was employed on the property for power purposes.

Design and Construction of Pipe Lines.—Petroleum is transported mainly by pipe lines, not merely within the confines of oil-fields but often to seaboard or shipping or railway centres hundreds of miles away from the source of its extraction. Long distance trunk lines often entail considerations that do not apply with equal force to the usual service mains of oil-fields covering distances of a few hundred feet to say twenty miles, and it is these latter which will be considered in this section.

Lapwelded or solid drawn pipes of a thickness to resist pressures far in excess of those projected are selected in lengths of from 20-30 ft. Screwed couplings with eight threads per inch and a taper of 3 per cent. are almost universally employed as

connectors. Where excessive corrosion is feared when passing certain country the whole pipe line is wrapped in bituminous sheeting, or painted with Angus Smith's solution or other protective paint prior to insertion in a trench.

In estimating the capacity of a pipe line and the pressure and power necessary to transmit a definite volume of oil through a pipe, it is necessary to know the static head, *i.e.*, the head due to difference of level between the points of intake and delivery, and from the velocity due to this quantity may be calculated the head required to overcome frictional resistance. Where there are bends, tees, or other connections, an additional frictional head is added, and this is usually expressed in an equivalent of so many feet of pipe. The usual formulæ for water are applicable to oil when corrected by the substitution of certain coefficients to suit various grades of oil handled.

Except in very short pipes it is unnecessary to consider velocity head, *i.e.*, the height through which the liquid must fall to acquire a velocity equal to that in the designed pipe line, equal to $\frac{v^2}{2g}$ when v = velocity in feet per second and g = gravity, also the head to overcome resistance to entry is usually quite negligible. Neglecting the latter a very satisfactory formula is :—

$$H = 4u \times \frac{L}{D} \times \frac{v^2}{2g},$$

when H = Head in feet due to friction.
L = Length of pipe in feet.
D = Diameter of pipe in feet.
u = coefficient that varies with viscosity of the fluid, for water and light oils = .0075.

Diagram 133A has been compiled from the above formula and gives at a glance all the essentials for ordinary pipe line calculations for tubes between 2 in. and 8 in. diameter. The secondary longitudinal curves enable data to be read off for certain velocities. The figures are only applicable to water and oils with viscosity of the same order, for the frictional resistances increase rapidly with oils that partially solidify through solid paraffin contents and those of the heavy asphaltic class. Calculations of "u" made from actual pipe line results show that this varies between .0075 and slightly

less for some very fluid light density oils to $6 \times .0075 = .0450$ for heavy viscous asphaltic oils.

In calculating the dimensions of pipe lines a substantial margin capacity should be allowed, either by excess area of main or excess power at the pumps, to allow for unforeseen contingencies and a possible diminution of the pipe capacity with age. Thus a pipe line in Roumania passed 2,700 barrels daily when new, but four years later only 2,300 barrels daily could be pumped through at the same pressure. If no sediment collects, no corrosion sets in, and no wax or mineral deposits are precipitated, the line may show some slightly improved capacity with age, on account of the removal of scale or particles of jointing material that reach the interior of the tube and present slight obstructions to flow.

The value of "*u*" for different oils or periods of operating can be calculated from pipe line figures. In a Roumanian pipe line 3 in. diameter, and 14 miles long, the value of "*u*" when working with light crude oil of .820 density was .0042. When a viscous paraffin-bearing oil of about equal density was pumped through the same line, the pressure was increased by 83 per cent. for the same quantity, and the value of "*u*" rose to .01.

A mixed 3-in. and 4-in. pipe line, 30,000 ft. long, through which .850 density oil was being pumped, gave the following results during a test of some duration during hot weather, the pipe line being on the surface:—

Average pressure at intake (pump)	202 lbs.
" " delivery end	26.7 lbs.
Discharge by measurement	21.5 tons (160 bls.) per hour.
Static head	285 ft.
4-in. pipe line	28,100 ft.
3-in. "	1,800 ft.

Area of 4 in. main = .08725 sq. ft.

$$21.5 \text{ tons of } .850 \text{ oil} = \frac{21.5 \times 2240}{8.5 \times 6.25} = 910 \text{ cub. ft. per hour}$$

$$= 0.25 \quad \text{"} \quad \text{"} \quad \text{sec.}$$

Velocity in 4-in. pipe line $= \dfrac{0.25}{.08725} = 2.86$ ft. per sec.

Area of 3-in. main = .0491.

Velocity in 3-in. line $= \dfrac{0.25}{.0491} = 5.1$ ft. per sec.

Total head $= 202 \times 2.3 = 466$ ft.

Static head $= 285$ ft.

Friction head (difference) $= 181$ ft.

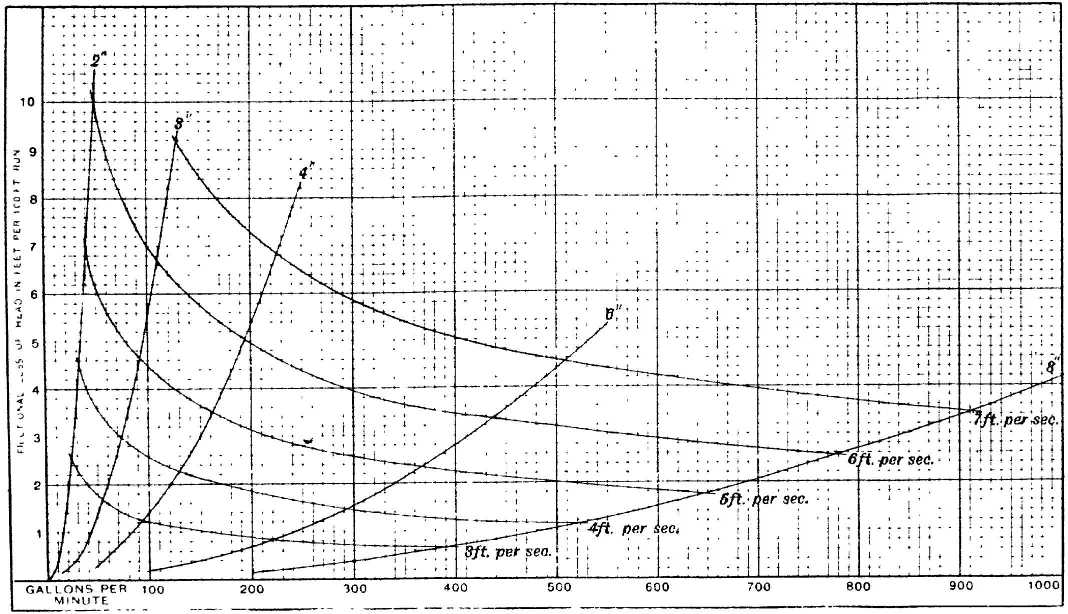


FIG. 133A.—PIPE LINE DIAGRAM SHOWING RELATIONSHIP OF FRICTIONAL LOSSES TO QUANTITY DELIVERED AND RATE OF FLOW

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Applying formulæ $H = 4\,u\,\frac{L}{D} \times \frac{v^2}{2g}$

$$181 = 4\,u \times \frac{28{,}100}{\frac{1}{3}} \times \frac{8.2}{64.4} = 42{,}824\,u$$

$$+ 4\,u \times \frac{1800}{\frac{1}{4}} \times \frac{26}{64.4} = 11{,}612\,u.$$

$$181 = 54{,}436\,u.$$

$$u = \frac{181}{54{,}436} = .0033.$$

The above unusual good results were probably due to the high temperature on a light oil.

Some tests on a 6-in. pipe line conveying Californian oil of .900 sp. gr. at 70° F. gave a value for "u" of .0147, and with a less viscous oil of .880 density the same pipe line gave a value of .0095 for "u." An Oklahoma buried pipe line, 3 in. diameter and 44,800 ft. long, conveying crude oil of a density of .855, and working at 70°-75° F., gave a value for "u" of .0089. Some Burma tests, where paraffin base oils are run, gave a value for "u" round about .011.

Viscosity is diminished in some cases by heating the oils before admission to the pipe lines, earth insulation assuring the maintenance of temperature for long distances where lines are deeply trenched. Surface lines are sometimes heated at intervals in their course, and in some cases congested pipe lines have only been released by heating with burning oil over long distances. Californian heavy grade oils are usually heated to a temperature of about 250° F. before admission to pipe lines, and the temperature is not allowed to fall below 100° F. without reheating. Wax-containing oils are likewise heated before admission to pipe lines to reduce viscosity, and in some cases light oils are added to keep in solution the paraffin contents within the limits of prevailing temperatures.

Fluidity is sometimes increased by the addition of hot or cold water to the oil, but the choice of water must be guarded or salts of lime may be deposited in the pipe and seriously impair the efficiency of pumping and the capacity of the pipe line. Several spiral or rifled pipe lines were designed and laid in California with the idea of reducing the high frictional resistances in pumping some of the heavy viscous oils of that country, but their success is uncertain. The tubing was grooved so that one complete turn

of 360° was effected in about 10 ft. of pipe, and it was claimed that the rotary motion thus imparted to moving liquids was sufficient to throw the heavier water to the outside, and enable the viscous oil to travel inside an annular ring of water. Water was added to aid this effect with alleged satisfactory results. No reliable data are available of proper tests, and it is suspected that the benefits did not justify the heavy outlay involved in the

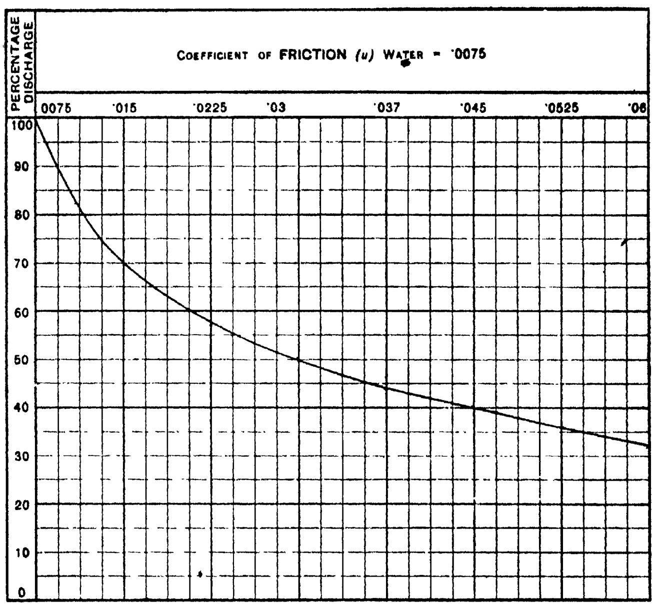

Fig. 134.—Diagram showing Percentage Ratio of Discharge for Oils with different Coefficients of Friction.

purchase of such expensive piping. In any case, it is difficult to believe that the centrifugal effect of a liquid moving at only 3-5 ft. per second with a twist so small would have any practical effect, but it is conceivable that water added at the inner surface of the pipe might tend to retain that position and be partially carried around with the rotating body of oil, thus reducing skin friction, in which case the more viscous and less miscible the oil the better the result in practice.

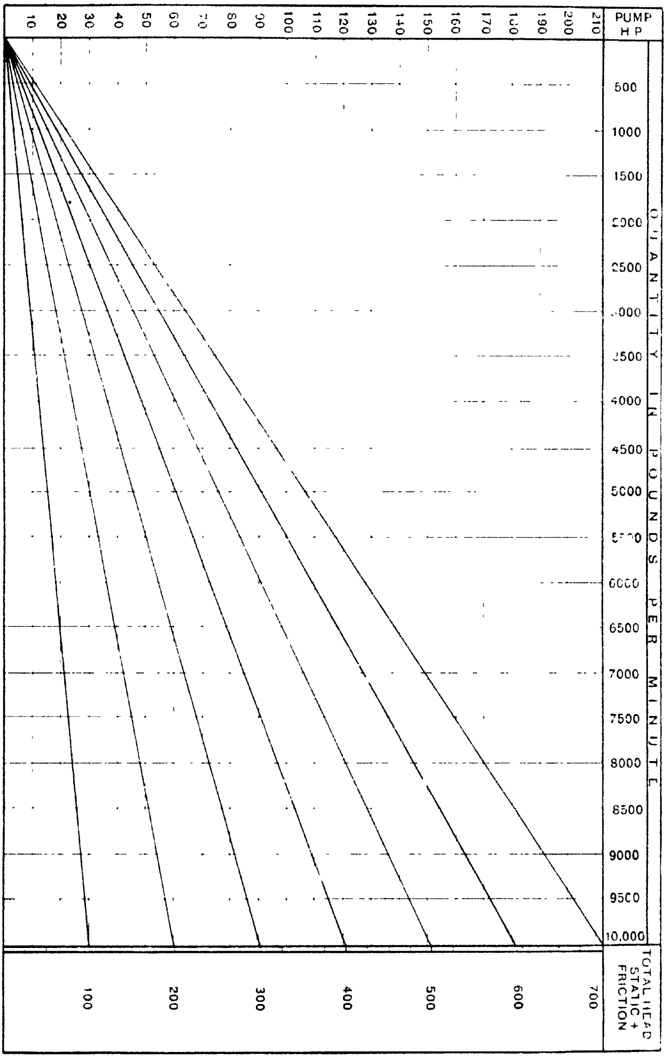

FIG. 135.—DIAGRAM SHOWING THEORETICAL HORSE POWER REQUIRED TO PUMP VARIOUS QUANTITIES OF LIQUID AGAINST VARIOUS HEADS.

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Sharp bends should invariably be avoided in pipe lines, and only full-way gate valves should be employed. When laid on the surface of the ground expansion joints must be inserted at intervals or serious leaks will develop with changes of temperature. Sometimes expansion is taken up by laying the pipe line in a sinuous course, thus enabling the line to better accommodate itself to expansion and contraction. This latter practice is not to be recommended although justified in certain cases.

In pipe line work the hydraulic gradient should be maintained, by which no point of the line is allowed to rise above the level drawn from the point of maximum elevation to the lowest point, and in pipe lines where light oils are pumped, it is necessary to provide for the release of gas that may collect at high points in the main and interfere with pumping. Automatic relief valves may be placed at such points to liberate gas so accumulating, or where low pressures are involved open stand pipes may be erected.

In temperate climates where summers and winters occur, all pipe lines should be sunk in trenches about 2-3 ft. deep. Streams may be negotiated, either by carrying the well-insulated main in boxes over trestles or bridges, or laying in the bed of the stream, in which latter case special river clamps are bolted over the sockets, and suitable anchors or supports are fixed to prevent any travel in the event of movements in the river bed. Pipe lines may be conveniently supported over ravines by suspension from wire lines stretched across and securely anchored at each bank. Suspension rods of suitable length allow the pipe to cross horizontally.

Trenches for long distance lines on easy gradients are now usually mechanically excavated with mechanically-propelled excavators that only require the services of two attendants. From 50-100 ft. can be performed in medium hard ground per hou[r] for depths up to 3 ft.

The power for pumping is simply calculated from the following:—

$$\text{Theoretical H.P.} = \frac{(\text{Static} + \text{Frictional head in feet}) \times (\text{pounds of liquid per minute}}{33{,}000}$$

Fig. 135 has been prepared to give at a glance the theoretica[l] horse power required to pump various quantities of liquid agains[t] various heads. In small field practice the power so obtained shoul[d]

be increased by 40-50 per cent. to allow for pump efficiency and contingencies, as in rough oil-field work there are many unknowns, and the pumps are often worked in a very inefficient state of repair. For ordinary duplex steam pumps it is advisable to allow for from 70-100 lbs. of steam per horse power per hour.

Fig. 43A, p. 287, can be used to facilitate calculations of weight of liquid from a certain specific gravity. Allowance must be made in calculations for any variation in density due to temperature.

An exceedingly useful chart is shown in Fig. 136 that enables one of three factors to be instantly read off if the other two are known. The chart shows gallons per minute, pipe diameter in inches, and velocity in feet per second. A line drawn through any two knowns will intersect the unknown and give the desired data.

The high development of the oxy-acetylene flame has led to its employment in welding up pipe lines in much the same way as steel rails are welded. Whether this process will ever compete with screwed sockets it is difficult to say, but it is certain that for special work in attaching branch connections under certain circumstances it might prove quite useful.

Deposition of wax in lines through which paraffin oils are conveyed reaches at times serious proportions, and its liberation and removal is undertaken with the use of a "go-devil." The "go-devil" is a tool with cutters that rotate when impelled forward by the pump after insertion in the pipe line. At intervals there are boxes into which the freed wax and the tool may fall before re-entry in a further length of line.

Damaged or corroded points in a pipe line are generally repaired, when discovered, by the attachment with bolts of a pair of clamps beneath which is inserted some soft packing unaffected by oil. Numerous devices are available for making branch connections without severing the line, for instance, by strapping on a combined clamp and screwed connection after a perforation has been made in the pipe. Pipe saddles are convenient connections.

Submarine Pipe Lines.—In recent years considerable attention has been given to marine pipe lines to effect shipments of oil from inconvenient points where shallow water would impose almost prohibitive expenditure on piers, and no deep water harbours exist near. Such submarine pipe lines have been successfully

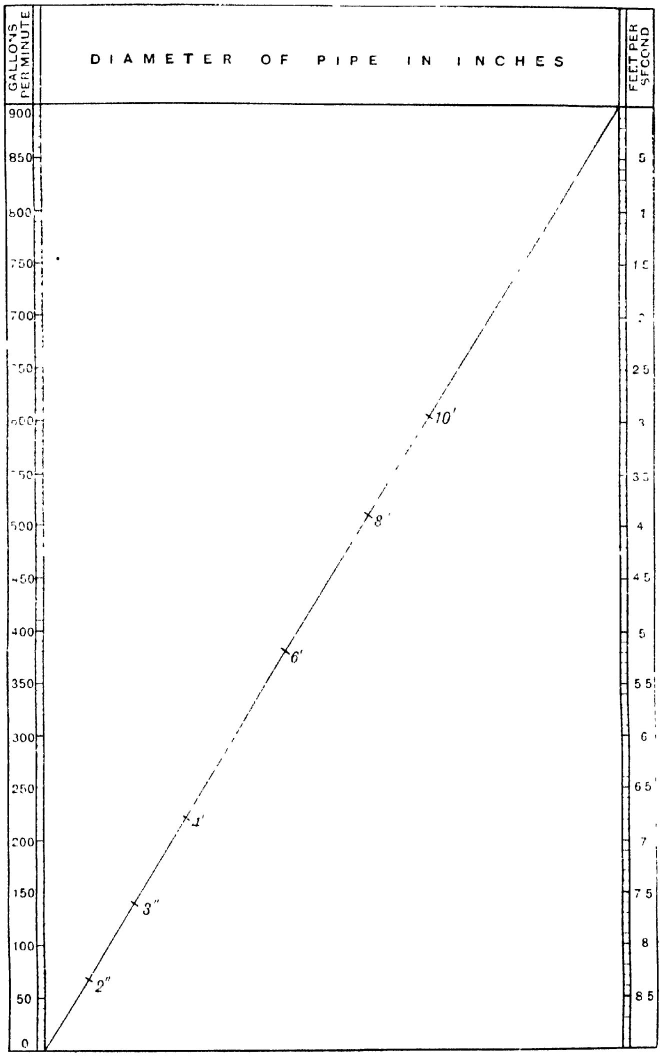


FIG. 136.—PIPE-LINE CHART ENABLING ONE OF THE THREE FACTORS TO BE DIRECT IF THE OTHER TWO ARE KNOWN, VIZ.

Imperial gallons per minute
Velocity in feet per second
Diameter of pipe in inches

By placing a straight edge across the two knowns the third may be read off at the point of intersection.

and operated in Mexico, Peru, Trinidad, the Caspian Sea, and other places. This class of work often involves careful surveys and engineering skill of no mean order unless failure is courted, as repairs are not cheaply effected, nor errors rectified.

Several methods have been adopted to suit local conditions. On flat level country the pipe line may be coupled up on the land and stretched on rails or rollers or other objects to reduce friction and then drawn out to sea by one or more tugs to the desired point. Where such a course is impossible the pipes are coupled up on barges or rafts and deposited as work proceeds. In the event of a rough sea developing whilst work is in progress the line must be plugged, sunk, and buoyed till the weather improves and work can be resumed. Where moving sands or beaches exist special anchor pieces must be attached to the socket protectors at intervals, thus sinking and holding the pipe line in position as sand is washed away.

In all cases it is advisable to attach heavy C.I. joint clamps to the collars to prevent a fracture at the joints during lowering on an uneven bottom, and to securely protect the joints from subsequent damage and breakages. All joints should be treated with a good bitumastic compound before attachment of the protectors. Divers may be necessary in some cases to examine the bottom and see the pipe line properly placed so as to avoid rocky irregularities, but usually this is unnecessary, and it is sufficient to attach to the end of the line a marine C.I. valve and fitting or concrete blocks to firmly secure the end piece to which the vertical ascending pipe is attached. No special derrick or dolphin is usually necessary at the sea extremity of the pipe line, where a flexible metallic piping or special canvas hose is either lowered on to the bottom and buoyed, or suspended from a winch on a barge or lighter.

The work of laying submarine pipe lines is facilitated by keeping them empty during laying, and so utilising the natural buoyancy of the enclosed air. A 6-in. pipe weighs with couplings and light protectors about 20 lbs. per foot, and the weight of water displaced would be about .25 cub. ft. per foot, or 15.6 lbs., consequently the weight of the submerged piping due to buoyancy would be 4.4 lbs. per foot instead of 20 lbs. The weight of the pipe, by the

addition of special strengthening clamps, is increased by about 50 per cent.

Pumps.—Until a few years ago single or duplex, direct-driven, reciprocating steam pumps were mainly used for water and oil services on oil-fields, but the advent of the internal combustion engine has led to the extended utilisation of belt, chain, or gear driven pumps. The turbine pump, developed from the old centrifugal, has likewise opened up possibilities where head and volume requirements fall within circumscribed limits imposed by that type. Direct-driven steam pumps need no description, as they are too well known to call for comment. They are wasteful in steam consumption, and very inefficient when slightly worn.

Reciprocating pumping sets, in which the source of power is either mounted on the same base plate or erected on separate foundations, are especially suitable for economical running by oil and gas engines or electric motors. The pumps may be of the ram or piston type, single or double acting, horizontal or vertical, and single, double, or treble throw. In selecting a pump, the following features should be observed where efficiency in running and reliability in use are not subordinated to initial outlay as is so often the case on oil-fields:—

(*a*) Moderate piston speed of engine and pump.
(*b*) Smooth running driving gear.
(*c*) Facilities for quickly opening up suction and delivery valves.
(*d*) Renewable valve faces as well as valves.
(*e*) Avoidance of pockets or receptacles wherein gas could accumulate.
(*f*) Where salt or corrosive water exist, gun-metal cylinder linings and valves and seatings should be specified.

Centrifugal or turbine pumps are particularly useful for large volumes where electric power is available for convenient direct coupled, high-velocity transmission, but the usual duty of small volume with high head has restricted their employment for pipe line work. For duties where large volumes of water contaminated with sand are required to be raised to small elevations for condensing or draining purposes, the pulsometer type of pump,

although extravagant in steam consumption, may with advantage be substituted for the centrifugal type where the latter cannot be conveniently operated. These have been successfully used in cleaning out large earthen reservoirs, and no difficulty has been experienced when the ejected mixture of water and sand contained quite a fair percentage of oil. Pulsometers have been utilised for raising sea water contaminated with sufficient sand to destroy reciprocating and rotary pumps, other than specially designed centrifugal pumps,

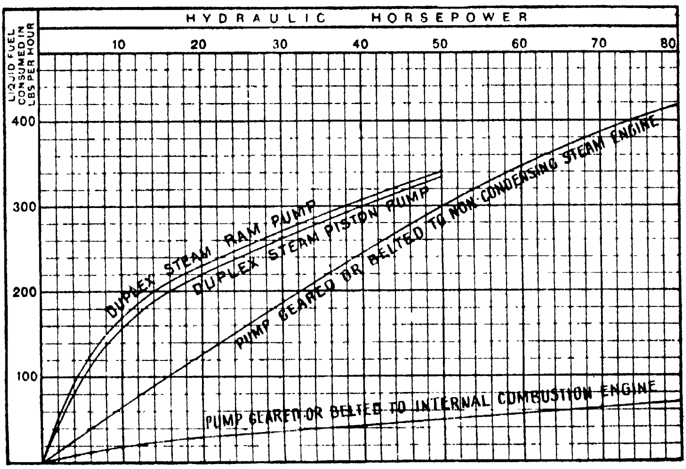


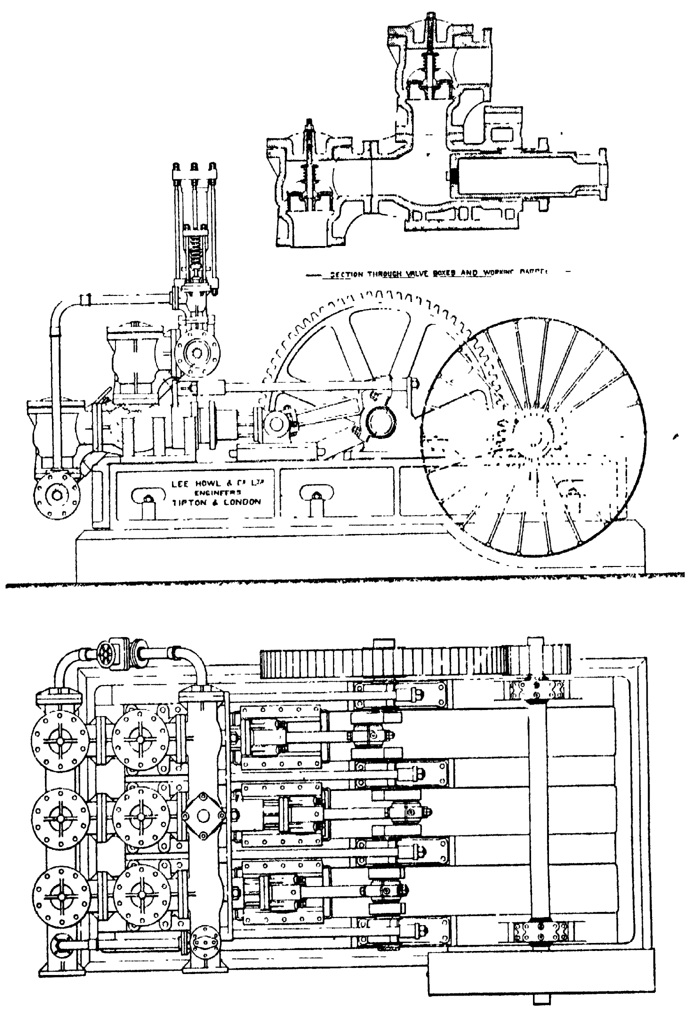
Fig. 137.—Diagram showing the Relationship between Hydraulic Horse Power and Fuel Consumption for Various Types of Engines and Pumps.

in a short time. The rise in temperature of the water is an obvious objection when water is needed for condensing purposes.

Drum pumps are quite suitable for low pressure work, and can with advantage be installed amidst groups of wells to force the oil, when free from sand, to main storages. They are usually driven by a belt with fast and loose pulleys from a pumping power engine.

Where wells are pumped by jerker lines it is possible to employ a pump operated by jerker lines to force the oil from a group of wells to some central storage.

High pressure long-distance pumping is almost invariably performed by ram pumps, often double acting with side coupling rods.



TRIPLEX PUMP FOR PIPE LINES

Fig. 138.—Typical High Pressure Gear-Driven Ram Pump.

These may be direct steam driven or be operated by any kind of power through the medium of a geared frame.

The power required for pumping is shown in Fig. 135; the fuel consumption per horse power naturally varies with the size and type of pumps, but may be taken approximately as follows. Fig. 137 diagrammatically shows the fuel consumption per horse power for various types of pumps.

Type of Pump	Fuel Consumption per Theoretical H.P. per hour at Various Capacities.
Direct-acting steam duplex pumps -	From 20 lbs. to 7 lbs. liquid fuel.
Oil engine geared with reciprocating pump - - - -	" 3 " 1 " "
Gas engine geared with reciprocating pump - - - -	" 20 cub. ft. to 12 cub. ft. gas.
Pumps geared or belted to non-condensing steam engine - -	" 8 lbs. to 6 lbs. liquid fuel.
Pulsometer type - - - -	" 30 " 15 " "

Handy portable pumps are now made for quick transference to deal with sudden flows of oil, especially when the latter is of light density, as the loss through even brief exposure to the atmosphere would be excessive. Fig. 138 shows a typical high pressure three-throw ram pump.

Measurement and Storage of Petroleum.—No universal unit of measurement has been accepted for petroleum. As a liquid petroleum naturally lends itself most readily to volumetric estimations, but on the other hand its variable density, when subjected to different temperatures, naturally suggests weight measurements as the proper course to ensure equal value under all conditions. As it is inconvenient to weigh liquids it is customary to measure oil volumetrically, and from carefully ascertained coefficients of expansion calculate corrections which can be applied to fix the weight of a definite bulk unit at any desired temperature.

At first sight it appears an easy matter to convert bulk into weight measurements, but extreme accuracy is very difficult as the coefficient of expansion varies with oils of different densities and composition, and sometimes layers of different densities separate in tanks. In practice, however, such details are neglected, and conversion tables are prepared and sold for the use of buyers and sellers. This coefficient of expansion is discussed on p. 288.

The ton is a unit of weight established by practice. In

England and America it is the 2,240 lbs. ton, but on the Continent of Europe it is customary to employ the metric ton of 2,204 lbs. (1,000 kg.). In Austria-Hungary and Roumania the car or wagon of 10 metric tons is a usual unit, and smaller quantities are often expressed in kilogrammes (2.2 lbs.). Russian weight measurements are in poods of 36 English lbs.

Volumetric units in general practice are the barrel and gallon. The American barrel, which has grown with the American oil trade, has a capacity of 42 American gallons. The following expresses the relationship of British and United States gallons.

United States gallon = 231 cub. in. = .833 Imperial gal. = 8.345 lbs. of water at 39° F.

Imperial gallon = 277.274 cub. in. = 1.200 United States gals. = 10 lbs. of water at 62° F.

The relationship of the United States gallon to the Imperial is therefore 231 : 277.274, and one barrel of United States 42 gals. is equal to 42 × .833 = 35 Imperial gals.

Measurements of oil are preceded by an examination for water, usually ascertained in tanks by the insertion of what is called an "oil thief," a graduated vessel to which liquid can be admitted when it is lowered to the bottom of the tank. A strip of chemically-prepared paper may be used, attached to a metal body that is lowered to the bottom of the tank, and as the paper is unaffected by oil and is by water, a line of demarcation is indicated. It is usually necessary to run off quite a quantity of oil mixed with water near the base of the tank to ensure freedom from water, but this is led through a water trap and from thence into a vessel or reservoir for more prolonged settlement and separation. Greater freedom from water and dirt in delivery of oil from tanks is aided by the use of a swinging delivery pipe, fitted with strainer, that floats or is slung near the surface of the oil, thus always drawing off oil from near the surface of the liquid.

Water contents of oil are quickly ascertained by agitating a sample with kerosene, and then allowing to settle in a graduated glass, or by the use of a centrifugal, whereby samples placed in graduated tubes are revolved at a high speed. Water contamination is often invisible, and with heavy oils a large percentage may remain obscured even after long standing.

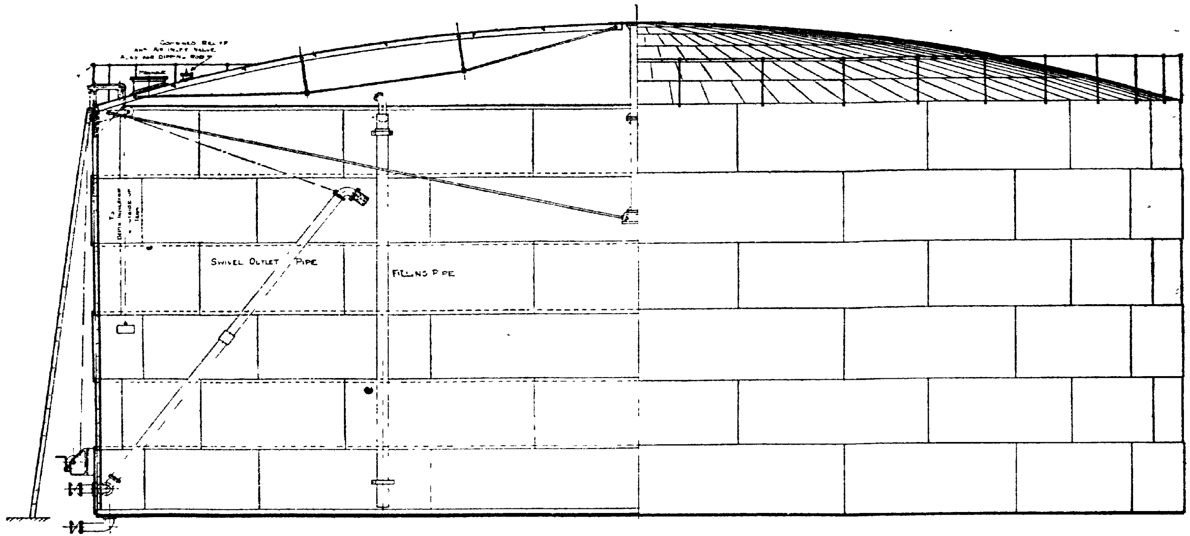


Fig. 139.—Typical Steel Oil Tank, showing all customary attachments and fittings.

Correct average densities of oil contained in receivers or tanks are determined by withdrawing samples at different depths by means of a small metal bailer or oil thief lowered to the desired point by a wire line or tape. The temperature is taken simultaneously with the density to ensure proper corrections for expansion to enable reduction to a common temperature. Crude oils that solidify with reduction of temperature, or are extremely viscous at temperatures approaching those prevailing in oil-fields, necessitate the use of a steam coil in the base of the tanks to effect fluidity when deliveries are to be made, and measurements are to be taken.

A steel measuring tape with a weight on its end is usually employed for oil measurements, but sometimes a wooden or steel rod is used for the purpose where the depth is not great. Floats and gauge glass readings are not usually sufficiently accurate for measurements of deliveries of oil, although useful as an index of level.

Oil is usually stored above ground in cylindrical steel or iron tanks of convenient proportions for requirements. A roof is provided to prevent admission of rain water and contamination, and in the case of light oils evaporation losses are diminished by the use of an air-tight roof, but in the latter case a special equilibrium valve is needed to allow the escape of gas if the pressure exceeds a predetermined safe degree, and to admit air when oil is abstracted. The main features characterising an oil tank are :—

1. Large draw-off valve at lowest point to remove water and sediment.

2. One or two manholes near base for entry.

3. Inlet pipe leading above top of tank, and either discharging on base or flowing into second large pipe that conducts new oil to the base of tank and prevents undue splashing, and consequently liberation of light products.

4. Gauge glass or succession of gauge glasses to read off oil level.

5. Sometimes a float and outside measuring board and indicator to notify level of liquid.

6. Floating or adjustable suction pipe to draw oil from top of liquid when discharging.

7. Sometimes for light oils in hot climates a water spray for roof or a dished roof for holding water.

8. The construction of an earthen embankment round the tank enclosing a space from one and a half to twice the volume of the tank so that in the event of a fire occurring the burning oil may be prevented from spreading.

9. All oil tanks should be well painted outside: the finishing coat should be white or nearly so in a hot climate to prevent undue absorption of heat.

10. Oil tanks, especially when intended for light gravity oil, should be very closely riveted, and great care should be taken to close the seams before the rivets are inserted and driven.

11. One or more dipping pipes, sometimes combined with the escape valves, are usually fitted for sampling.

The cost of steel tankage naturally varies with the price of metal and labour, but for standard sized tanks the price varies from \$0.45 per barrel of capacity for 1,000 barrel tanks to \$0.15 per barrel for 30,000 barrel tanks, after which the price per barrel of capacity diminishes but little.

Oil-fields are usually provided with service tanks of assorted sizes for such purposes as settlement of sediment or water, temporary local storage, measurement of oil from individual wells or isolated units of wells, fuel, or feed water. As they are principally for duties of a temporary nature it is advisable that they should be of a weight, dimension, or nature that admit of transfer from place to place. Exceedingly serviceable wooden tanks or vats are largely used in the American, Roumanian, and Russian oil-fields, where until recent years they were remarkably cheap. The staves are supplied in bundles, with edges planed, and the base timbers are likewise correctly cut and shaped to fit in grooves in the staves. When set up the staves are tied together by steel bands with screws that draw them firmly round the tanks.

Wooden tanks of the above kind can be easily conveyed in bundles of inconsiderable size and weight to any point, and their dismantling and re-erection is a simple matter at any time. If shaded from direct sun's rays by a surround of brushwood, or protected from vertical rays by a larger wooden cover extending

far beyond the edge of the tank, evaporation losses are surprisingly small.

The list below gives the particulars of a few convenient sizes that are in popular request on oil-fields.

PARTICULARS OF WOODEN TANKS OR VATS.

Diameter in Feet.	Length of Staves in Feet.	Capacity in Gallons.		Shipping Weight in Lbs.
		American.	Imperial.	
6	4	700	840	590
8	4	1,300	1,560	840
8	8	2,800	3,360	1,370
10	4	2,000	2,400	1,120
10	8	4,300	5,150	1,800
12	4	2,900	3,480	1,400
12	8	6,200	7,430	2,300
14	8	8,500	10,200	2,800
14	14	15,400	18,500	4,300
16	16	23,000	27,600	5,700
18	16	29,000	34,800	6,700
24	16	52,000	62,400	10,400

Circular steel tanks, 8 ft. diameter and 4 ft. high, are largely employed for oil-field duties. They have an upper angle-iron curb riveted inside, two angle-iron braces and several 2-in. outlet connections at several points near the base. Such tanks can be rolled on their sides from site to site without sustaining damage. Their cost at ordinary times is about £12 ($60).

Sometimes tanks are leased or rented for the storage of oil. The Roumanian Government charged F. 8,000 (£320 = $1,600) per annum for 4,000 tons storage tanks at Constanzia, and in the United States a charge of 1 cent per barrel (3.75 pence per ton) per month is customary. In England, charges of 6d. per ton per month have been made.

Cause, Prevention, and Extinction of Fires.—Oil-field fires can best be attacked by water notwithstanding the first impression that water might be the least valuable and possibly most dangerous to use. The author spent several years of the most dangerous period in the Baku oil-fields of Russia, when every new well saturated the neighbourhood for long distances with highly inflammable vapours, and careless, ignorant labour neglected the

most obvious precautions against fire, and unwittingly took the most reckless risks in efforts to evade legal restrictions. Fires were in consequence of constant recurrence, and many involved hundreds of derricks and many acres of congested oil properties.

Little risk of extensive damage occurs in oil-fields where the wells are widely distributed, but where several wells per acre are located the congestion of works and difficulties of access and egress constitute a real and serious danger to property and life. A recent example of the extreme danger arising under such circumstances is afforded by the Moreni-Bana oil-field of Roumania, where a whole succession of fires time after time devastated the area and caused serious loss of life, notwithstanding official restrictions of a drastic nature. This field lay in a depression protected from certain winds, and the light crude oil, yielding as much as 40 per cent. of benzine, was accompanied by prodigious quantities of exceedingly inflammable gas when wells were flowing. Explosions were severe and a slight misadventure would initiate a big conflagration.

A fire service should be arranged on congested properties, and usually the high pressure oil pumps are used for feeding the mains at a pressure that will throw a jet at least 150 ft. Care must be taken to so arrange the piping that oil is not left in, as on several occasions the author has seen oil fed to the fire jets with disastrous effect. Stand pipes should be erected at intervals, clearly marked, and hoses should be placed at suitable spots beneath a shelter for their preservation. Trials should be made occasionally, and positions allocated to certain men with fixed duties near at hand. A powerful whistle or hooter should immediately be sounded in the event of fire to warn all workmen who could not observe an outbreak.

Fires not due to incendiarism arise mainly from the following causes:—

Lightning.

Heating of some moving part of the machinery.

Sparks through striking of metal or stones when a well is in eruption, or strongly gassing.

Breakage or short circuiting of electrical apparatus.

Ignition of travelling or creeping gas.

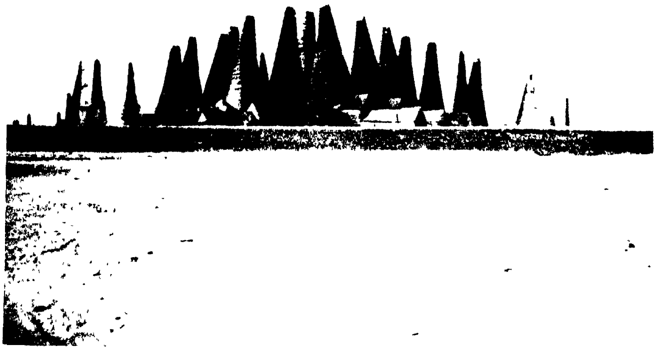
In districts where thunderstorms are frequent fires occasionally arise from lightning, the derricks and tanks naturally constituting

particularly likely objects for attack. Differences of opinio are held concerning the use of lightning conductors. As light ning conductors frequently prevent a stroke of lightning by silent neutralisation of earth and cloud electricity their use migh be beneficial. The risk is not usually considered of sufficier importance to take special protective measures, although a larg tank installation might, with advantage, have a tall mast fitte as a lightning conductor near the tanks that would deflect possible discharge away from a dangerous centre, or relieve electric tension. Fires by lightning are especially prevalent each summe in Oklahoma and Galicia, and in the former fields it has bee observed that they originate from ignition of gas far above th tank or derricks, and operators now lead a gas pipe from tank to a distance. In Galicia steam jets are opened in derricks durin thunderstorms.

Overheating of brakes or bearings can best be prevented b leading jets of water to points where danger exists. In very gaseou wells water should be led to brake bands and measures should b taken to *methodically* attend to the lubrication of all working parts

Sparks are frequently caused by the striking of the too against the casing or other metal parts of the rig. Usually th temperature is insufficient to ignite gas or inflame oil, but at tim sparks do cause explosions for some unknown reason. Freque fires have originated through this cause with serious loss of life one field with which the author is professionally associated, a where the oil contains nearly 50 per cent. of benzine; consequentl it can be positively affirmed that sparks can be a source of conside able danger. In one case an explosion occurred in the casi during drilling, of sufficient violence to drive a wrought-iron cov sheet to the top of the derrick, where it was embedded in t timbers; and the author has had brought to his notice many cas of explosion in wells during drilling. Usually these explosions a not very violent on account of the incorrect admixture of air produce the most explosive mixture.

The most dangerous point is near the mouth of the well wh the requisite admixture with air is possible, and the danger can greatly minimised by inserting copper rings, or attaching wood clamps, so that the upper length of casing is not struck by to



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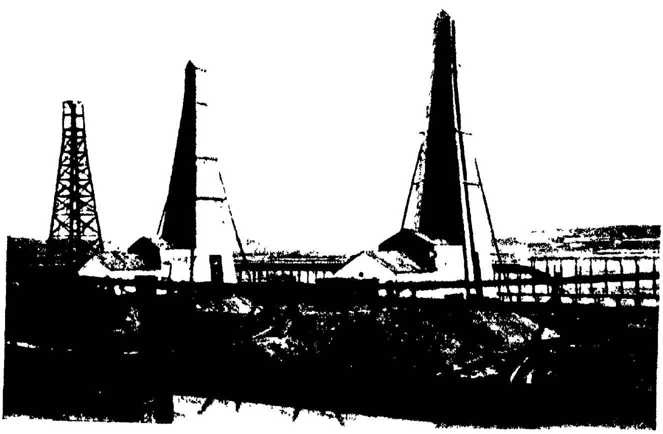

B

FIG. 140.—PROTECTED DERRICKS.

A. Group of Derricks in Baku Oil-Fields protected with Sheet Iron (also shows the excessive congestion on a plot of small area surrounded by unallotted Government lands).

B. Derricks protected by Uralite Non inflammable Covering.

[To face page 500.

during their ascent, descent, or working. During bailing, a jet of steam may be allowed to impinge on the mouth of the well in the absence of a copper or wooden ring.

Eruptive wells occasionally take fire through siliceous stones striking one another, or steel objects obstructing their path. That the former is possible is exemplified by the ignition of natural gas ejections such as have occurred near Baku, Russia, and are described fully elsewhere.

Failure of electric service has been a source of so many fires, that it is now a custom to place outside the derrick a switch that can be shut off if a well flows and endangers the structure or the fittings. The lamps themselves are always protected by glass and wire globes, but incandescent filaments rarely ignite gas, although they may. Short circuits are more dangerous, as the derrick itself may be fired.

Petroleum gases are heavy, and during calm weather the gas may creep unnoticed along the ground until it reaches a boiler furnace or fire, when ignition takes place, and the flame travels quickly to the source of origin. Such an occurrence led to a serious loss of life on Plot XIX., Bibi-Eibat, Russia, on one occasion when a well was flowing far away from the boiler house. It is now a common practice in congested fields to install large fans for drawing the gas from the derrick during big eruptions, and expelling it through tubing to a point outside the danger zone.

It is difficult to confine an oil-field fire to a single well in a congested area, and all property lies in great danger when there is an outbreak, especially if there are flowing wells in the vicinity. Wooden derricks are now often covered with sheet iron, uralite, or some other non-inflammable material, which prevents ignition from falling sparks, and restricts the extent of the fire by reducing sparking if a well so provided is ignited. An additional safeguard is often provided by installing a water spray round the top of the derrick, and in some cases, in addition, a steam outlet valve in the derrick. This latter causes jets of steam to emerge from every crevice or space in the derrick, and these will repel and extinguish burning particles that may approach or settle near dangerous spots.

All oil tanks, chutes, or other vessels should be provided with covers to prevent burning fragments carried by winds from settling

on exposed oil. Men should be stationed at numerous points with shovels to throw soil or sand on any burning object that falls on the property. When the danger is serious, soil or sand should be thrown on all machinery, and it will usually be possible to dig it out intact after a fire if well covered in this way. The author has had in operation within forty-eight hours engines so protected although buried in burning debris.

The extinction of burning gushers is described elsewhere, p. 458.

Oil tanks are sometimes protected by water sprays, and for safety to the neighbourhood they are always surrounded by an earthen or masonry dam that will give a capacity in excess of the tank or tanks thus surrounded. More recently foam mixtures have been used for extinguishing burning oil in tanks or reservoirs. Two tanks are prepared, in one of which is placed a mixture of glue, glucose, bicarbonate of soda, salicylic acid, and water, and in the other a mixture of aluminium sulphate, sulphuric acid, and water. The two are introduced into a common mixer and the resultant foam ejected on the surface of the burning oil. The evolved carbon dioxide is retained by the foam formed, and so kept in contact with the surface of the burning oil, effectively preventing admittance of air and absolutely extinguishing the fiercest flames at once.

An improvement in the above process has been effected by using some of the by-products of the manufacture of liquorice, especially rich in resinous and albuminous materials, that form a foam of considerable durability.

Mechanic Shop and Buildings.—All large oil properties are equipped with a mechanic shop where repairs may be executed, and special tools manufactured. The size and amount of machinery naturally depends upon the magnitude of the enterprise, but the minimum plant for a properly designed shop would be :—Lathe, pin and socket lathe with hollow spindle and tapering attachment, two drilling machines, shaper, screwing machines, fan and smith's plant, with power hammer.

A workshop designed by the author's firm for an oil property is shown in Fig. 141, where it will be seen that, besides the ordinary machines, there is a multiple spindle drill for preparing perforated

PLATE XXXIX.

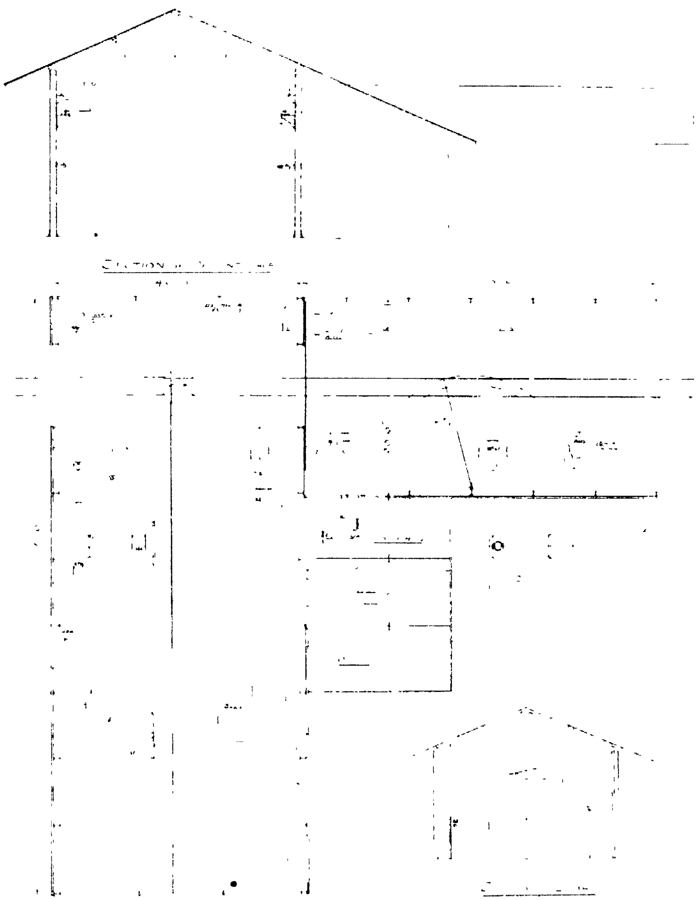

FIG. 141.—TYPICAL MECHANIC SHOP FOR AN OIL PROPERTY
(Designed by Thompson & Hunter.)

Tools in Shop

2 Lathes	1 Multiple Spindle Drill	2 Forges.
1 Hollow Headstock Lathe	1 Screwing Machine (bolts)	1 Grindstone
1 Radial Drill.	2 Screwing Machines (casing)	1 Steam Hammer
1 Standard Drill	1 Shaper	1 Fan

[To face page 502.

casing, and screwing machines for taking all sizes of casing in use. The hollow-mandrel lathe is a very useful tool, and should never be omitted, as it enables the boxes of long stems to be rebored and screwed without the necessity of cutting off and rewelding the joint after machining; a costly and unsatisfactory procedure where the blacksmiths may not be highly skilled. Such supplementary tools as power hacksaw and keyway cutter are useful labour-saving additions.

Workshops are usually constructed of steel when sent abroad to places where timber is scarce or expensive, but for dwellings timber is usually and naturally preferred. In temperate climates no special kind of structure is necessary, and the local prevailing style is customarily adopted, but in the tropics the subject assumes a far graver aspect for people from temperate zones, as upon the type of dwelling largely depends the health of the staff. The author has paid especial attention to this subject, and particularly studied the Panama methods during successive visits to the Isthmus during the progress of the canal works. As the *Anopheles* and *Stegomyia* mosquitoes, the only conveyors of malaria and yellow fever respectively, have nocturnal and domestic habits, breeding readily around houses, and immediately seeking the dark recesses of rooms, it is essential that all dwelling houses should be screened; screened double doors enabling admission and exit, with a minimum of risk of intruders entering. Fig. 142 shows a bungalow designed for the tropics, incorporating all the main features for health and comfort under trying tropical surroundings. All verandahs are screened with bronze metallic netting, and all water tanks and vessels are similarly screened. A second precaution is a mosquito net to all beds in addition. If the site of erection is situated on elevated ground no inconvenience is experienced, as is so often asserted, through the screening reducing air currents. The escape from the annoyance of myriads of flying insects, which at night trouble all tropical residents in unscreened houses, is itself a comfort not to be despised. As the *Anopheles* only appear at night, the risk of infection is very small if the evenings are spent in screened buildings.

In this connection a few hints on road construction and transport in new countries might not be out of place, as transport

is not infrequently one of the chief sources of outlay in distant, uninhabited regions, perhaps covered by dense jungle. In muddy, forested regions the undergrowth should be first cleared and the route surveyed to avoid great differences of elevation. As few big trees as possible should be felled, as the roots have to be dug out. The route is next deeply trenched on either side for drainage, and then corduroyed by laying suitably split timber or hardwood saplings side by side across the track; sand, burnt clay, or other available material being then laid on its surface. The corduroy is anchored at its two edges by cross pieces held down by firmly driven stakes. Burnt clay can be prepared by stacking up alternate layers of good hardwood logs and clay. On being fired, slow combustion proceeds for a week or more, and the clay is burnt to brick, making a fine road covering for light traffic.

Bridges are built from rough-dressed trunks of hardwood, supported on bearers resting upon firmly placed pedestals. A selection of steel girders has been found very useful for bridging small streams in pioneering. Bad pieces of swamp can often be traversed by piling up bundles of brushwood, and soft muddy stretches can be negotiated by means of buffaloes and sledges. In sandy regions, like parts of California, the liberal use of oil has greatly facilitated transport; and in other regions asphalt roads have proved of great value. Motor traction is usually impossible for such pioneering work, but light railways of the Decauville type have proved invaluable in developing oil-fields where plant has often to be conveyed many miles from the port of embarkation or rail head, or where the operations are some miles distant from the workshops and residences of staff.

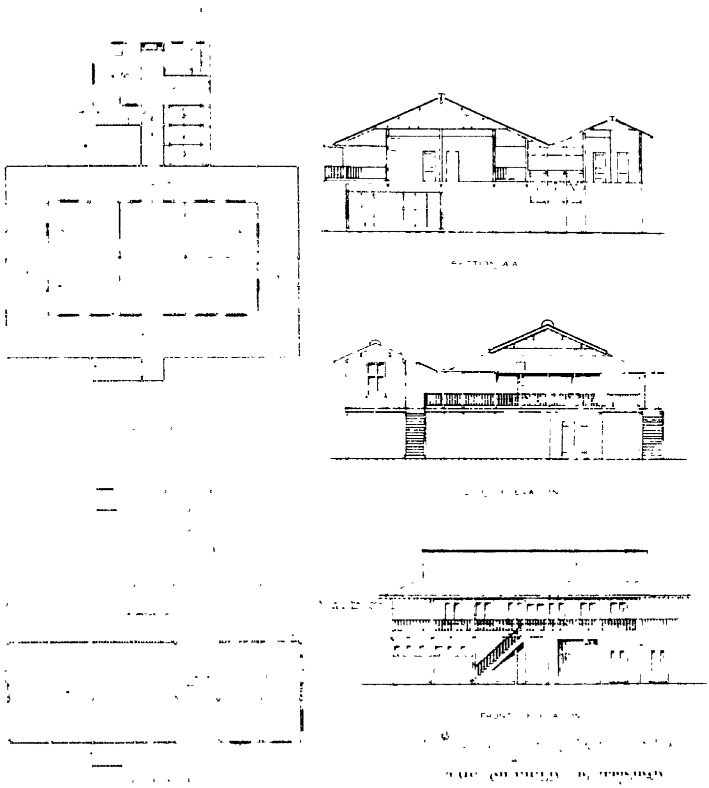

Fig. 142. Typical Tropical Bungalow.
(Designed by Thompson & Hunter.)

Specially designed for malarial climates to secure maximum circulation of air and to exclude mosquitoes and other insects. All verandahs are screened with bronze gauze, and springs are affixed to doors. Double entrance doors are usual.

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CHAPTER XII.

THE MEASUREMENT, COLLECTION, TRANSMISSION, AND UTILISATION OF NATURAL GAS.

Natural Gas—Collection of Natural Gas—Measurement of Flow of Gas—Combustion of Natural Gas—Gas-Gasolene Extraction.

Natural Gas.—The conditions under which natural gas occurs in Nature, and the phenomena associated with its distribution, have been fully described in the preceding chapters.

Analyses and calorific values of natural gases from widely separated oil-fields have been given in Chapter VI., and some idea of the waste of this valuable fuel can be gleaned from the figures on p. 93.

Extensive use is made of natural gas in the United States, and around Pittsburg most of the great iron and glass works extensively employ gas, which is often obtainable at 10 cents (5d.) per 1,000 cub. ft. Some of the gas mains leading to Pittsburg have a diameter of about 36 in., and a daily capacity of over 100,000,000 cub. ft. The pressure in the mains from the gas-fields is often several hundred pounds per square inch, but it is reduced to about 4 oz. (of water) in the city distributing mains.

In the Canadian gas-fields the gas is likewise led, under a pressure of 200 lbs. per square inch or thereabouts, to the centres of consumption, where it is distributed at a pressure of from 2-6 oz. per square inch to the consumers. In the city of Chatham, in 1907, the charges for natural gas were as follows:—

Lighting and cooking -	35 cents	per 1,000	cub. ft.
Heating up to 100,000 cub. ft. - - -	27 "	"	"
Heating from 100,000 to 150,000 cub. ft. - -	22 "	"	"

Heating above 150,000 cub. ft. - - -	17 cents per 1,000 cub. ft.
Gas engines - - -	15 „ „ „
Firing boilers - - -	12 „ „ „

Natural gas, comparatively free from nitrogen and carbon dioxide, may be considered to have a calorific value of about 1,000 B.T.U. per cubic foot, from which it can be deduced that from 19-20 cub. ft. of gas are equivalent in heating value to 1 lb. of crude oil, or 42,500-45,000 cub. ft. of gas as equal to a ton of oil.

Enormous volumes of natural gas, available at nominal prices within practicable distances of the great industrial centres of Pennsylvania, have been an important factor in the mineral development of those regions, notwithstanding the prevalence of cheap coal. In participating in a discussion of this subject,[1] the author presented the following figures that showed the enormous advantages that accrued from cheap natural gas. Gas at 15 cents (7½d.) per 1,000 cub. ft. was equivalent in heat units to good coal at $4.80 (£1) per ton, and crude oil at $6.75 (28s.) per ton, but if the average price of gas for power purposes of 9 cents per 1,000 cub. ft. is taken, the gas is equal in heat units to coal at $2.88 (12s.), and crude oil at $3.84 (16s.) per ton.

Comparing the cost of power with the contemporaneous prevailing conditions in England, the following comparative figures are obtained :—

Coal gas	at 2s. (48 cents) per 1,000 cub. ft.	=	25,000 B.T.U. for 1d. (2 cents).
Producer gas	at 2d. (4 cents) „ „	=	75,000 B.T.U. for 1d. (2 cents).
Natural gas	at 4½d. (9 cents) „ „	=	220,000 B.T.U. for 1d. (2 cents).

Heat units available from public gas companies in London thus cost nearly nine times as much as in Pittsburg.

Converted into cost of power at 12 cub. ft. per B.H.P.-hour for natural gas, and 18 cub. ft. for coal gas per B.H.P.-hour, and 80 cub. ft. of gas per B.H.P.-hour for producer gas used in gas engines, there is obtained :—

[1] Bulletin 125, Inst. Min. Metallurgy, London. Discussion on "Inflammable Natural Gas as an Economic Mineral," J. A. L. and W. A. Henderson.

Natural gas	at 9 cents per 1,000 cub. ft.,		13s. 6d. ($3.24) per B.H.P. year of 3,000 hours.
Coal gas -	at 48 cents	„ „	108s. ($26.00) per B.H.P. year of 3,000 hours.
Producer gas	at 4 cents	„ „	40s. ($9.60) per B.H.P. year of 3,000 hours.

Used for steam generation in a medium-sized non-condensing engine the comparative cost of power is :—

Natural gas	at 9 cents per 1,000 cub. ft.,	£3. 5s. per B.H.P. year of 3,000 hours.
Coal - - -	at $4.80 (£1) per ton,	£4. 8s. per B.H.P. „ „ „

In practice, however, it is found that a larger margin must be allowed, and in the Baku oil-fields, where the theoretical heating equivalent of 1 pood (36 lbs.) of crude oil is 728 cub. ft. in natural gas, it is found that about 770 cub. ft. are consumed under the boilers to replace this amount of crude.

One of the chief difficulties connected with the utilisation of natural gas is its transportation over long distances. A large pipe line transporting 30,000,000 to 50,000,000 cub. ft. daily entails an expenditure not much less than a railway and engineering problems of little less importance. The thermal units conveyed are small compared with the transport of oil. A 12-in. pipe line would conveniently convey over long distances 1,000,000 cub. ft. of gas per hour representing in rough figures 1,000,000,000 B.Th.U., but the same line would be able to transport over 200 tons of oil, or, say, 9,000,000,000 B.Th.U. per hour, corresponding to nine times as much power. Put another way, a 4-in. pipe line, costing but a fraction of that of a 12-in., would easily transmit as oil the equivalent in heat units of the 1,000,000 cub. ft. of gas; the latter being equal in calorific value to about 22 tons of oil. The natural gas diverted to commercial use in America, in 1912, was estimated at 562,200,000,000 cub. ft., valued at $84,564,000 (£17,617,000). An average price of 26.34 cents was charged to domestic consumers, and 9.11 cents to users for industrial purposes.

Methane is usually the predominating hydrocarbon in oil-field gases all over the world, but sometimes there is also a proportion of other hydrocarbons present. A quantity of extremely light spirit condenses from the gas issuing from some wells, and collects in the mains, from whence it must be periodically

abstracted ... depressed point, or in a trap placed for its reception.

A test of one sample of such spirit showed a specific gravity of 0.755 at 60° F.

A natural gas of ordinary composition only becomes explosive when it is mixed in the proportion of from 6-12 per cent. with air, the critical percentage and most explosive point being reached with a mixture of 9.6 per cent. methane with air.

Such a diluted mixture of gas could never be approached in usual oil-field operations where ordinary precautions were adopted, but nevertheless the simple precaution of arranging a water seal outside boiler houses and points of consumption should never be omitted, where there is the possibility of air gaining access to the gas mains.

In those cases where exhausters are in use, and there is the possibility of air being drawn into the mains in large quantities, the additional precaution of a wire gauze near the mouth of the burner should be taken, a back fire into the mains being thereby impossible unless the gauze became overheated or an explosion occurred in the furnace chamber of the boiler when lighting up, which would cause the flame to leap past the gauze. The interposition of an explosion valve near the burner saves the main from damage.

The proportion of air and gas cannot readily be ascertained, nor can the proportions be automatically registered, and the composition of the mixture in the gas mains can only be determined by a test in an Orsat apparatus, or some such-like appliance.

Collection of Natural Gas.—When wells are sunk exclusively for gas and no petroleum exists, the gas, when registering a high pressure, is usually conducted direct into mains which lead either to centres of industry or to large compressors, where it is forced under still higher pressure to industrial points. If sand or water accompany the gas, some form of separator should be installed to intercept these before admission to the long distance mains. When the pressure has decreased, and the output of gas has considerably diminished, an increased yield is obtained by drawing the gas from the wells, and in many cases maintaining at the mouth of the well a partial vacuum.

In the great Appalachian gas-fields which have contributed so largely to the prosperity of Pennsylvania, the diminishing volumes of gas and smaller pressures registered as a result of gradual exhaustion have led to the installation of enormous gear-driven exhausters and compressors for impelling the gas under high pressure to areas of consumption such as Pittsburg and Cleveland.

Increased attention is now being displayed towards the employment of natural gas issuing from oil wells, where till recently few attempts had been made to preserve and utilise this valuable source of energy in the important oil-fields of the world.

In the collection of natural gas several important points must be considered when the outflow of a number of wells is led under natural earth pressure to a single main, otherwise considerable losses may result. Whilst the closed pressures of two or more wells after an interval of rest for the establishment of equilibrium may coincide, the open pressures of the same wells may vary considerably on account of different subterranean conditions which retard or favour the movement of gases. The pressure in an open main is fixed by the resistance, and if the flow of gas is such as to raise the pressure in the main above the natural earth pressure of one or several of the wells, gas will flow from the high pressure wells to those indicating a low earth pressure, the total yield being diminished instead of augmented by the connection of such wells. This phenomenon has been demonstrated by the author by actually testing individual wells, and then ascertaining the combined flow when coupled up, the results being the reverse of those anticipated on account of the absorption of gas from the higher pressure wells by the lower.

A back flow of gas may be prevented by attaching a check valve at each well where the supply is in excess of demand, in order to seal up paths of possible loss, but if the whole available supply of gas is needed, the mains must be sufficiently large to avoid a pressure exceeding that of the lowest well pressure, when no check valves will be needed. Where the pressures are very low, a partial vacuum is often maintained in the mains by an exhauster, thus assuring the maximum yield of gas from any group of wells.

Collection of Gas from Pumping Wells.—Where wells are

operated by means of the deep well pump the collection of gas is a simple matter, as it is led away from the side outlets on the casing head at the mouth of the well to points of consumption, or drawn from thence by exhausters.

Collection or transportation of gas from a group of widely separated wells is most easily accomplished by installing at each well a small reciprocating gas pump operated by a rod from the walking beam or a connection from the jerker line. By adjusting the stroke of the gas pump, any desired discharge can be arranged according to the volume of gas yielded by the well.

A large amount of gas always escapes with the oil in pumping wells, and where great economy of fuel is exercised it is a practice to fix gas tanks at each well into which the discharge pipe of the oil pump flows. Gas tanks are simply constructed, and consist of cylindrical iron drums, into the top of which is conducted the discharge pipe of the pump and from which a gaspipe emerges. The oil, from which the gas separates while discharging into the tank, collects to a certain height in the tank before its outflow commences, and the level of oil is automatically maintained near a fixed point above the exit pipe by a float, syphon, or some other device which controls the discharge cock. Fig. 143 illustrates a useful type of gas tank.

Where the variations in pressure are not great, a gooseneck connection at the bottom of the tank for the oil outflow is sufficient to create a seal and prevent the escape of gas, but if the well is liable to "blow," this method, of course, could not be adopted, as the pressure of gas would probably exceed the liquid "head" of the gooseneck, and the oil and gas would be blown out of the tank.

Wells which make periodical flows from the pump tubes whilst being pumped often yield great volumes of gas, which may be recovered by the aid of gas tanks fixed in the manner indicated.

The yield of gas from pumping wells varies greatly. New wells may yield from 40,000-1,000,000 cub. ft. per day, whilst old wells, or those sunk in less prolific fields, may only yield from 5,000-20,000 cub. ft. daily.

Collection of Gas from Bailing and Swabbing Wells.—The collection of gas from oil wells which are being bailed, and consequently have a free outlet at the surface to the atmosphere, is not

such a simple operation as with pumping wells, but nevertheless it can be performed if suitable provision is made for sucking the gas away. To ensure comparative freedom from air, the gas must be drawn from bailing wells some distance from the surface, as the alternate ascent and descent of the bailer in the well and the

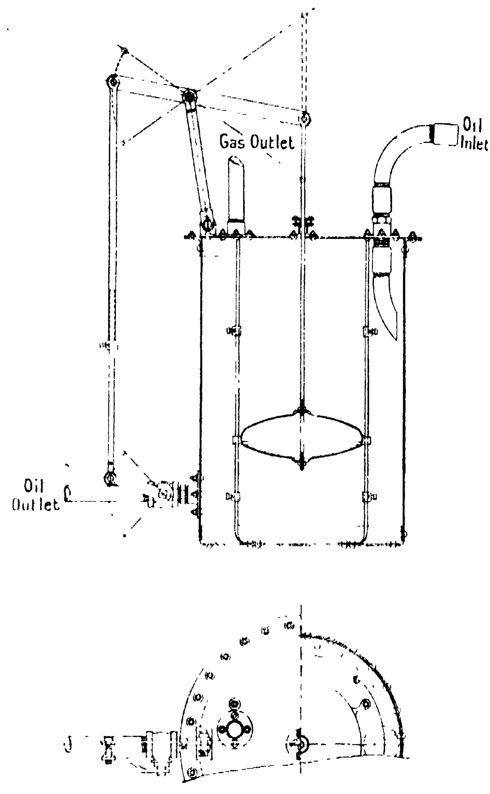


Fig. 143.—Gas Tank or Separator.

agitation suffered by the liquid encourages the irregular liberation of the gas, making it necessary to allow sufficient "cubic" above the gas intake to compensate for these fluctuations.

In completed wells, where no suitable preparation for the collection of gas can be made, a tube is inserted through the casings as far beneath the surface as possible, and then led to an exhauster which draws away the gas; but a better plan is to perforate the

last string of casing at a depth of 100-200 ft. below the surface, so that the gas can enter the space between the casings and be drawn from thence by some form of exhauster. If the annular space between the casings is sealed at the surface, air could only be admitted by being drawn down the central casing of the well from the surface.

As bailing wells invariably exhibit a widely fluctuating yield of gas, it is necessary to provide a cock or valve on the suction pipe for adjusting the area of the intake, and it is further advisable to have an indicator to show if air is being drawn in from the surface. A simple method is to direct a minute jet of steam over the mouth of the well, when the direction of the flow of gas can be instantly observed at any moment by the deflection of the steam.

If it is important to collect gas without any admixture of air, the intake must be so adjusted that some gas always issues from the mouth of the well; but as there is no objection to a small proportion of air for many purposes, the cock can be so adjusted that a little air is drawn in also, reducing thereby the loss of gas to a minimum.

The collection of gas from a group of bailing wells not far separated from each other can most economically be effected by having a common suction main of ample dimensions into which the various intakes are led from each well. A partial vacuum is maintained in the suction main by some form of exhauster, the character of which depends upon the volume of gas to be dealt with, and the pressure needed on the delivery side. For large volumes of gas, with a delivery pressure of only a few inches of water, a fan or blower is best adapted, but for smaller volumes of gas and a higher delivery pressure a Root's blower or reciprocating compressor is preferable. Where large volumes of gas have to be forced to pressures of several pounds per square inch a turbo-blower is the best form of exhauster to employ.

In the design of a large installation by Thompson & Hunter to deal with 1,000,000 cub. ft. of gas daily, arrangements were made for drawing the gas from the wells by means of an exhaust steam turbine, direct coupled to a turbo-blower, through a main encircling the oil property, and delivering under 7 lbs. pressure to a battery of boilers. The maintenance of a constant vacuum was

assured automatically by a device by which any rise in the vacuum controlled the steam regulator.

Small turbo-driven fans may with advantage be placed at isolated wells for dealing with low pressures, but usually for the extraction of gas from widely separated wells, and its transmission to points of use, a small reciprocating compressor, driven by belting from a countershaft or some part of the machinery, may be used with advantage.

Galician wells that are swabbed often have provision arranged for drawing off by exhausters the gas that emerges with the oil. The mixed product is led into a receiver, above which is a column from which the disengaged gas is drawn.

Wells in the Baku and Grosny oil-fields of Russia, where bailing is chiefly practised, give widely fluctuating volumes of gas, but an average of the yield of old and new wells would probably not be far short of 30,000 cub. ft. daily. New wells often yield not less than 500,000 cub. ft. daily, but wells which have settled down to a normal state give usually from 30,000-60,000 cub. ft. daily.

The Collection of Gas from Air-Lift Wells.—The gas escaping from air-lift wells can be conveniently collected in the same way as from wells pumped by a deep well pump, but it is necessary to ascertain that the gas so collected is not mingled to a dangerous degree with air which, especially in the case of intermittent action, often finds admission into the well.

Air-lift discharges vary considerably in composition, according to the volume of air used and the character of the oils raised, but a highly inflammable mixture is nearly always generated as a consequence of the intimate association and agitation of the air and oil. Besides the normal gases which always issue from oil when freshly drawn from subterranean sources, a proportion of other hydrocarbons are liberated as a result of the fierce agitation which proceeds in the air-column, and a richly carburetted air mixture often results.

In oil-fields where the oils are light the carburetted mixture from air-lift plants may be led direct to the boiler furnaces after being directed through a tank where the oil can separate, but there is considerable danger that moments may exist when the proportions of air and gas reach an explosive limit.

The author had brought to his notice an explosion which originated in this way and caused considerable damage, although the system had been in successful operation for several months without an accident, no one having apparently realised the danger that existed, as no water seal had even been interposed in the delivery gas mains.

Carburetted air can more safely be used by admitting the mixture to large mains conveying pure gas in considerable quantities, the percentage of air never then approaching dangerous proportions.

Unless the output from air-lift wells is intelligently directed to use there are great risks of an explosion, and no attempts should be made in that direction without qualified assistance.

Measurement of Flow of Gas.—The yield of gas wells can be measured by ascertaining the pressure at which the gas issues through a circular orifice of known area and calculating the velocity therefrom. When high gas pressures are registered in an open tube, an ordinary pressure gauge may be attached to a length of bent tubing, the open end of which can be held vertically over the mouth of the well; but for low pressures an ordinary U tube or water gauge can be applied in the same way, and the pressure read off in inches of water or other fluid inserted in the U tube.

In general practice a modified form of water gauge is often used, known as the Pitot gauge, tube, or instrument, which is not only applicable to gas yields from open orifices, but also for ascertaining the velocity of gas in mains.

The Pitot tube is an instrument for determining the velocity of a current of liquid or gas flowing either in an enclosed tube or open duct, or discharging into the atmosphere.

It is composed of a bent tube with an orifice directly opposing the direction of flow, and also a side orifice to equalise any difference of pressure due to static head. It is attached by a piece of flexible tubing to a U gauge or other type of pressure gauge, and there registers the difference of pressure due to velocity head.

The liquid used in the U gauge may be either water, kerosene, alcohol, or mercury, according to the amount of pressure to be

measured, or in the usual spiral of a Bourdon pressure gauge for high pressures above, say, one atmosphere, when the dimensions of a U gauge with mercury would become inconveniently large.

The formula for the measurement of gas flowing from an open orifice, such as the mouth of a well casing, can be expressed as follows :—

If h inches represent the height of a column of gas of specific gravity s (air = 1), equivalent to a displacement h^1 inches of liquid of specific gravity s^1 in the legs of the U gauge.

Then $hws = h^1w^1s^1$, or $h = \frac{w^1}{w} \times \frac{s^1}{s} \times h^1$ inches, where w is the weight of 1 cub. ft. of air, and w^1 that of 1 cub. ft. of water.

Assuming the truth of the formula for the velocity of a liquid issuing from an orifice due to head h, $v^2 = 2gh$, and inserting the value of h found above, we get the velocity—

$$v = \sqrt{2g\frac{w^1}{w} \times \frac{s^1}{s} \times \frac{h^1}{12}} \text{ feet per second.}$$

Careful experiments have been made for testing the truth of this formula, applied to the practically frictionless orifice of a Pitot tube, and it has been proved correct.

Having obtained the velocity, all that is required is to multiply it by the cross-sectional area of the pipe in square feet to obtain the volumetric discharge in cubic feet per second.

There are some practical considerations in the use of the Pitot tube which must be attended to in order to obtain reliable and consistent results.

Firstly, the mouth of the opening to which the tube is applied must be even, so as to avoid creating eddy currents due to uneven area of discharge, and for this purpose the length of the portion of the pipe to twenty times its diameter should be free from bends, joints, U pieces, and other connections which tend to create eddy currents, that is to say, the pipe should be straight, smooth, and its mouth should be free from burrs.

Secondly, should the area of the pipe be large for the quantity of gas passing, so as to prevent a reading of a velocity pressure, it should be reduced until a convenient size has been reached to give an accurate reading.

Thirdly, measurements of flow taken at atmospheric pressure must be free from "adiabatic" flow in the tube, whereby the pressure at the mouth of the tube is considerably above atmospheric pressure. The tube should be placed at the mouth of the orifice, and not in it nor away from it. Readings on the U gauge are generally small, and it is convenient to use kerosene as the liquid, as it is lighter than water and offers less resistance to friction on the sides of the glass.

A formula analysed, given in Bulletin 88 of the Bureau of Mines, Washington, is as under:—

$$Q = 5773.68A\sqrt{\frac{WH}{\text{weight of cub. ft. air}}} \times \text{sp. gr. of gas.}$$

Where Q = quantity of gas in cubic feet per minute.
A = area of gas main in square feet.
W = weight of water in lbs. per cubic inch.
H = velocity head in inches of water.

A formula devised by Mr A. A. Ashworth that has given trustworthy results in practice is:—

$$V = 29\sqrt{\frac{D^5(p_1^2 - p_2^2)}{L \times S}}.$$

Where V = volume in cubic feet per hour.
D = diameter of pipe in inches
S = density of gas compared with that of air.
p_1 = absolute pressure of gas at inlet in lbs.
p_2 = absolute pressure of gas at outlet in lbs.
L = length of pipe in miles.

The constant 29 is low for clean new pipes, where it might be raised to 33 in some cases.

The measured quantities should be increased by a suitable percentage to allow for air before proceeding to calculate sizes of mains.

Having determined approximately the daily output of gas from the group of wells, calculations must be made for selecting the proper diameter of suction main. The loss in friction for air or gas along a wrought-iron pipe can be taken at 1 velocity head per

every 32 diameters of pipe, the velocity head h being equivalent to $\frac{v^2}{2g}$. Thus the friction loss in a pipe l feet long and d inches in diameter is $\frac{l}{32} \times \frac{12}{d} \times h \times s$, where s is the specific gravity of the gas (air = 1).

To reduce this to inches of water pressure it is necessary to divide by 68, since 68 ft. represents the column of air at atmospheric pressure and 60° F. corresponds to one inch of water pressure, and we get the friction loss—

$$\frac{l}{32} \times \frac{12}{d} \times \frac{v^2}{2g} \times \frac{s}{68} \text{ inches of water.}$$

The maximum suction to be maintained in the main to overcome friction, as calculated above, should be increased by a few inches of water to create flow at the well.

Such calculations as the above are useful in deciding one upon the type of machine to employ. Exhausters cannot maintain a very high suction, but can handle large volumes delivering at low pressure. Reciprocating pumps and compressors maintain a very high vacuum on the suction side, which increases the velocity of flow, but requires greater power. This higher vacuum renders the use of large suction pipes less necessary, but often on oil properties there are to be found many lengths of old or damaged casing of large size, which may very well be used for gas suction mains, so that the cost of outlay in piping does not enter into account to such a degree, and it is then a problem of economising in power for the compressor or exhauster. The frictional resistance in the discharge main of an exhauster or compressor is generally provided for by the formula—

$$d = \sqrt[5]{\frac{Q^2 l}{p}} \times 0.07,$$

where d is the diameter of the main in inches, Q the cubic feet of gas per hour passing, l the length of main in yards, and p the pressure in the main in inches of water.

Table XVII. shows the flow of gas in cubic feet a day from pipes of various diameters between 1 in. and 6 in. diameter under different pressures. The volume of gas is calculated at 32° F., and the specific gravity is taken at 0.6, air being unity.

TABLE XVII.—FLOW OF NATURAL GAS, IN CUBIC FEET PER DAY, FROM VARIOUS-SIZED ORIFICES.

Observed Pressure by Mercury Gauge, in Inches.	Observed Pressure by Water Gauge, in Inches.	Observed Pressure by Pressure Gauge, in Lbs. per Square Inch.	Diameter of Orifice or of Well Mouth where Observed.						
			1 Inch.	1½ Inches.	2 Inches.	3 Inches.	4 Inches.	5 Inches.	6 Inches.
...	.1	.0036	12,390	27,880	49,556	111,510	198,220	309,750	446,040
...	.2	.0073	17,560	39,510	70,260	158,040	281,040	439,000	632,160
...	.3	.0109	21,480	48,330	85,940	193,320	343,760	537,000	773,280
...	.5	.0182	27,720	62,370	110,880	249,480	443,520	693,000	997,920
.05	.7	.0254	32,820	73,940	131,260	295,380	525,050	820,400	1,181,520
.07	1.0	.0364	39,210	88,230	156,830	352,890	627,310	980,400	1,411,600
.11	1.5	.0545	48,030	108,070	192,120	432,270	768,480	1,200,800	1,729,100
.15	2.0	.0727	55,340	124,520	221,360	498,060	885,440	1,383,600	1,992,200
.22	3.0	.109	67,910	152,800	271,630	611,190	1,086,510	1,698,000	2,444,800
.29	4.0	.145	78,410	176,420	313,660	705,690	1,254,620	1,960,400	2,822,800
37	5.0	.182	87,670	197,260	350,670	789,030	1,402,670	2,193,600	3,156,100
.52	7.0	.254	103,500	232,880	414,000	931,500	1,656,000	2,587,600	3,726,000
.74	10.0	.3636	123,000	276,750	492,000	1,107,000	1,968,000	3,075,000	4,428,000
1.02	13.75	.50	146,220	328,990	584,880	1,316,000	2,339,500	3,655,500	5,864,000
1.52	20.62	.75	175,350	394,540	701,400	1,578,150	2,805,600	4,384,000	6,312,600
2.03	27.5	1.00	201,800	454,010	807,200	1,816,050	3,228,500	5,044,600	7,264,200
3.05	41.25	1.5	247,840	557,650	991,370	2,231,000	3,965,000	6,196,000	8,922,000
4.07	55.0	2.0	285,130	641,540	1,140,500	2,566,200	4,562,000	7,128,000	10,265,000
5.08	68.75	2.5	316,500	712,130	1,266,000	2,848,500	5,064,000	7,913,000	11,349,000
6.10	82.50	3.0	344,350	774,780	1,377,400	3,099,100	5,510,000	8,609,000	12,397,000

7.12	[illegible]	3.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8.13	110.0	4.0	393,000	884,250	1,572,000	3,537,000	6,288,000	9,825,000	14,148,000
8.15	...	4.5	415,270	934,350	1,661,100	3,737,400	6,644,000	10,382,000	14,950,000
10.17	...	5.0	436,200	981,450	1,744,800	3,925,800	6,979,000	10,905,000	15,703,000
11.18	...	5.5	456,200	1,026,500	1,824,800	4,105,900	7,299,000	11,405,000	16,423,000
12.20	...	6.0	473,750	1,065,900	1,895,000	4,264,000	7,580,000	11,844,000	17,055,000
13.21	...	6.5	489,840	1,102,100	1,959,400	4,409,000	7,837,000	12,246,000	17,634,000
14.23	...	7.0	505,920	1,138,300	2,023,700	4,553,300	8,095,000	12,648,000	18,213,000
15.25	...	7.5	522,010	1,174,500	2,088,000	4,698,000	8,353,000	13,050,000	18,792,000
16.26	...	8.0	538,500	1,211,600	2,154,000	4,846,000	8,616,000	13,462,000	19,386,000
18.30	...	9.0	565,970	1,273,200	2,263,000	5,093,000	9,054,000	14,147,000	20,371,000
20.33	...	10.0	589,270	1,325,900	2,357,100	5,303,000	9,428,000	14,372,000	21,214,000
24.39	...	12.0	633,340	1,425,000	2,533,300	5,700,000	10,133,000	15,833,000	22,800,000
28.46	...	14.0	675,000	1,508,800	2,700,000	6,075,000	10,800,000	16,875,000	24,300,000
32.53	...	16.0	713,550	1,605,500	2,854,200	6,422,000	11,415,000	17,839,000	25,688,000
36.60	...	18.0	748,650	1,684,500	2,994,600	6,738,000	11,978,000	18,716,000	26,951,000
40.66	...	20.0	779,350	1,753,500	3,117,400	7,014,000	12,470,000	19,484,000	28,057,000
50.81	...	25.0	845,150	1,901,600	3,381,000	7,606,000	13,522,000	21,129,000	30,425,000
61.00	...	30.0	902,180	2,029,900	3,609,000	8,120,000	14,435,000	22,555,000	32,478,000
71.16	...	35.0	954,820	2,148,300	3,819,000	8,593,000	15,277,000	23,870,000	34,373,000
...	...	40.0	998,680	2,247,000	3,995,000	8,988,000	15,979,000	24,967,000	35,952,000
...	...	45.0	1,036,700	2,332,600	4,147,000	9,330,000	16,587,000	25,918,000	37,321,000
...	...	50.0	1,072,000	2,412,000	4,288,000	9,648,000	17,152,000	26,800,000	38,592,000
...	...	55.0	1,106,880	2,495,000	4,428,000	9,962,000	17,710,000	27,672,000	39,848,000
...	...	60.0	1,137,600	2,559,600	4,550,000	10,238,000	18,101,000	28,440,000	40,953,000

For temperature of flowing gas where observed of 30°, 40°, 50°, 60° F., add 4, 3, 2, 1 per cent. respectively.

To change the result by this table to that for any other specific gravity of gas other than 0.6, multiply by $\sqrt{\frac{0.6}{\text{Sp. gr. gas}}}$.

Should 98 per cent. alcohol be used in gauge, multiply the readings by 0.8 to reduce to water value.
Should .75 specific gravity kerosene be used in gauge, multiply the readings by .75 to reduce to water value.

Corrections for other densities or temperatures of gas can be made as indicated.

The yield of gas wells can be approximately estimated from the capacity of the bore hole in cubic feet, and noting the increase in pressure in one minute after the outflow is closed.

$$Q=\frac{d^2\times 3.1416\times L}{4\times 144}\times\frac{p}{15}\times 60, \text{ or } Q=\frac{1}{46}d^2Lp.$$

Q = cubic feet of gas per hour into atmosphere.

d = diameter of well in inches.

L = depth of well in feet.

p = pressure in lbs. shown in gauge one minute after closing valve, less any pressure which may have been indicated before closing valve.

If the discharge is needed at any other pressure than that of the atmosphere, the increase of pressure is noted during the minute after the desired pressure has been reached.

There is always a perceptible, and frequently a considerable decrease in the yield of gas from oil wells when bailing or pumping is suspended, and in the case of bailing wells, where measurements of output can only be made on a cessation of bailing, the measured flow is often far below the actual normal yield. In such estimations, therefore, one can always consider the measured results to constitute a minimum.

The normal flow of gas from ordinary bailing and pumping wells is so small that no pressure is recorded on a common water gauge, and the area of orifice must be decreased until a head can be read. In wells lined with screwed casing this end can be best achieved by introducing into the well a tube about 10 ft. long, to which is attached a disc flange near the upper end, beneath which a piece of insertion is placed to make a tight joint between the casing collar and the flange. If no pressure is then recorded a smaller tube may be inserted inside the latter.

In the case of wells of large diameter, where often riveted casing is used, and there is an escape of gas through faulty joints near the surface when the pressure rises, it is necessary to lower a disc on the tube some distance down the well to avoid the leakages which are sure to take place where the casing is not encircled by earth. A gas-tight joint may be made above the

disc by covering it first with cotton waste, and then sand and clay until no escape of gas occurs.

Combustion of Natural Gas.—Where natural gas exists under considerable pressure, and it is led direct to centres of utility, the pressure is automatically reduced from the main to from 3-6 in. of water before admission to the distributing mains for general supplies. Where, however, the gas is led direct from gas wells under a pressure of many lbs. per square inch to power houses, it is often burnt direct in the boiler without the use of any form of burner, or the provision of any special furnace front, the natural force of the gas inducing sufficient draught of air to the burner to readily support combustion. Where the gas pressure does not exceed a few ounces per square inch some form of

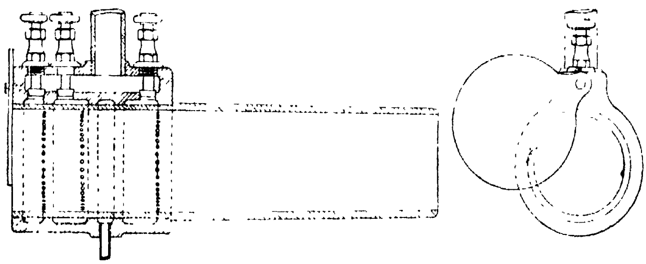


Fig. 144.- Gwynne Gas Burner.

burner is necessary, whereby the gas and air are intimately commingled and the mixture burns as in an ordinary Bunsen burner. Fig. 144 shows a popular form of American low pressure gas burner which possesses all the main qualities demanded to secure perfect combustion of the gas. The gas is admitted from an annular chamber to the internal portion of the burner through numerous small orifices arranged spirally and at an angle, so that the gas issues at an angle and is given a swirling motion, and becomes intimately commingled with the air induced through the burner. The correct amount of air is secured by adjustment of a door on the burner front, and the gas supply is regulated by the gas cocks. In the burner illustrated there are three rings of holes of different sizes, each connected with an independent cock, so that gas with pressures of an ounce to 10 or 12 ounces of water can be economically burnt. The holes on the front

circle are $\frac{1}{8}$-in. diameter for pressures between 4 and 8 ounces of water, the second circle are $\frac{1}{16}$ for pressures below 4 ounces, and the third are $\frac{7}{64}$-in. holes for pressures above 8 ounces. By opening all the cocks full the burner will give its full power with 1 ounce of pressure, and by using a steam jet gas can be drawn into the burner.

Where it is not desirable to place any back pressure on the wells, the gas is often exhausted slightly by a steam injector, which also induces the necessary draught of air to produce combustion.

A gas burner designed to deal with low pressure gas is the "Hunter," illustrated in Fig. 145. A partial vacuum is caused at the nozzle by a jet of steam that not only accelerates the flow of

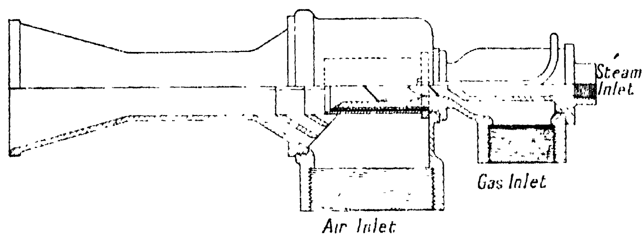


Fig. 145.—"Hunter" Gas Burner.

gas, but induces an inrush of air to support combustion. By means of vanes the air and gas are given a swirling movement that aids rapid and effective combustion when both are adjusted to admit the correct proportions.

With a steam pressure of 60 lbs. it is possible to produce a vacuum of 1 lb. sufficient to overcome the friction of a considerable length of piping, thus enabling gas to be drawn from wells where not placed too far away.

There is an erroneous impression prevalent in some oil-fields that gas alone without steam acts injuriously on boilers; also that pressure alone will not cause effective combustion. Where there is a pressure of only 12 in. of water, .943 lb. per square inch, complete combustion is possible with the aid of nothing more than a flattened piece of piping as a burner. So transparent is the flame at times that, but for the incandescent state of the furnace lining, it would be

impossible to say from an observation of the fire-box whether the boiler was under fire.

The theoretical amount of air required for the combustion of gas can be calculated from its analysis, in the same way as oil has been treated in Chapter XI. Assuming a gas of .650 density (compared with air) to contain 78 per cent. by weight of carbon and 22 per cent. of hydrogen, the air required for combustion would be 16.4 lbs., or 220 cub. ft. per lb. of gas. The volume of 1 lb. of the gas would be $\frac{13.4}{.65} = 20$ cub. ft., consequently $\frac{220}{20} = 11$ cub. ft. of air, would be required per cubic foot of gas for complete combustion.

Gas-Gasoline Extraction.—The high commercial value assigned to oils of light density, vaporising almost entirely below a temperature of 150° C., has fostered the extraction of light hydrocarbons that usually accompany most oil-field gases, and especially those associated with light gravity oils. Those gases, mainly composed of methane, whose critical temperatures preclude their commercial liquefaction, are generally known as "dry," whilst others which yield from 1-4 gals. of liquid per 1,000 cub. ft. of gas under pressures of from 50-500 lbs. per square inch are referred to as "wet," for the purpose of classification. There is no line of distinction between the two, and the term admits of no scientific definition, as many gases commercially "dry" do yield some condensates at certain temperatures and pressures.

Investigations have shown that the chief gaseous products which condense under moderate pressure and practicable reduction of temperature are of the paraffin series; indeed, normal pentane (C_5H_{12}), hexane (C_6H_{14}), and heptane (C_7H_{16}); but even these have vapour tensions at atmospheric pressure that prevent their commercial use in practice unless absorbed by heavier and more stable hydrocarbons. For the commercial extraction of liquid hydrocarbons it is necessary that there should be a fair percentage of products whose vapour tension does not cause their entire evaporation when briefly exposed to the atmosphere. Experience has shown that there is no need to "weather" the "wild" liquids to secure reasonable stability, as intimate admixture

with oils of heavier density leads to their partial absorption and retention in a way that gives the gasoline a low flash point, but yet does not cause excessive pressures in receptacles.

The process is exceedingly simple in principle, but in practice there are numerous points requiring skill, judgment, and experience if success is to be achieved. The gas is usually compressed in a compound compressor with intervening coolers to a pressure of from 200-350 lbs. per square inch, or sometimes only 50 lbs. per square inch in a single compressor, and the product is led into a condenser or refrigerator from which the liquefied products are drawn. An exceedingly low temperature may be attained by allowing the dry gas to expand in a vessel through which the compressed gas is conducted in its passage to gas mains or to the atmosphere. Gas engines using the treated gas are generally employed for operating the plant, so that, apart from initial capital cost, running expenses are low when gas is cheap.

So many failures resulted from the installation of gas-gasoline plants that the United States Bureau of Mines was induced to study the problem, and the painstaking investigations of Messrs Russell, Gilbert, Oberfell, and others have served to elucidate many difficulties, and to standardise tests that were previously very imperfect and misleading.

Gas compositions were usually estimated from volumetric measurements of burnt gases in a eudiometer, but this was quite unsuitable for the more accurate analysis required of gases to be treated for condensible products. The Bureau of Mines has now recommended the titration of gases with claroline oil, which has the power of absorbing paraffins, especially those fractions higher in the series, consequently the volume dissolved gives some clue to the adaptability of natural gas for gasoline treatment. The Bureau of Mines affirms that methane (CH_4) is soluble to the extent of 10 per cent., and pure ethane to the extent of 68.5 per cent. in claroline oil of .8667 sp. gr. at 15° C.; flash point, 152° C. (Pensk*y*-Martens test).

Isolation of the hydrocarbons constituting natural gas was effected by the Bureau of Mines by distillation at low temperatures,

the gas being first liquefied by means of liquid air, and then separated by distillation *in vacuo* at various temperatures. A gasoline-yielding gas tested in this way gave—[1]

Methane	36.8 per cent.
Ethane	32.6 ,,
Propane	21 0 ,,
Butane	9.5 ,,
Pentane	
Hexane, etc.	

Gas may be tested for specific gravity, a heavy density suggesting a fair proportion of the denser, higher paraffins, but this is not a sufficient guide to its constituents, as nitrogen and carbon dioxide may be present and confuse deductions. The best way of ascertaining the value of natural gas for gasoline extraction is to make an actual test with a portable plant. Gases used in the United States for treatment have a density exceeding 1.00 and a solubility in alcohol or claroline oil of 50-80 per cent.

Natural gas escaping under high pressure is less rich in condensible products than gases flowing under atmospheric pressure, or more often a partial vacuum, although at times considerable quantities of oil vapours are carried by the gas and condense in mains. Wells subjected to a pressure below that of the atmosphere yield the richest gases, due to the release of hydrocarbons that would otherwise remain in the oil in a liquid dissolved state, and which would often be lost in the operations of pumping, transporting, and storing the crude.

Without an exact analysis of the gas or an actual test it is impossible to approximately foretell the quantity of liquid that can be abstracted from a gas, nor can the pressure required be safely estimated. If the condensate were one product only, say pentane mixed with a definite proportion of methane, it would be possible to fix the quantity of condensate and the pressure required. In a mixture of 10 per cent. pentane and 90 per cent. methane by volume a pressure of $\frac{11.8}{.10} = 118$ lbs. would be necessary to produce condensation at 30° C., taking the vapour pressure of

[1] "The Condensation of Gasoline from Natural Gas," by Messrs Burrell, Seibert, and Oberfell. Bureau of Mines, Washington, United States, America.

pentane at 30° C as 11.8 lbs. per square inch. The volume liquid obtained per 1,000 cub. ft. gas would be $\frac{1}{10}\frac{1000}{31}=\frac{100}{31}=3.2$ gals., assuming 1 gal. of pentane yields 31 cub. ft. gas at 0° C. *With mixed gases it is impossible to determine the pressure needed to condense a definite percentage volume.*

Complicated issues result from the working of compressor plants. Increased pressures may effect enhanced yields of condensates, but *the extra volume may be of the "wild" nature* and useless for all *practical purposes owing to its volatility and consequent* loss immediately it is placed under atmospheric pressures. Not merely is the lighter material lost, but in its escape other heavier and commercially valuable products may be carried away too. Against this must be placed the ascertained property of some condensates to carry in solution large quantities of methane and ethane which are found in subsequent analyses of the gasolines. The American Bureau of Mines refers to plants where about 35 cub. ft. of gas disappear per gallon of condensate, but in other cases 50 per cent. and more of the gas disappears without increased quantities of condensate.

The exact state of gases dissolved in liquids is not understood. It is thought that they occupy some intermediate stage between gases and liquids, as it is difficult to consider them in a liquid condition when their critical temperature is not reached. Reduction of temperature enables liquids to absorb a larger volume of gas, which excess, however, is expelled again on elevation of temperature. Then again, certain distillates absorb larger volumes of gases than others, and this subject has been little investigated as yet.

Gasoline plants must be operated to suit individual requirements. Less pressures are needed to produce the main stable products that are derived when there are no large quantities of refining distillates with which to mix the produced material. On the other hand, intimate admixture of light condensates with large volumes of benzine distillates may lead to their entire absorption and retention. The "weathering" of products too light to have any but the most restricted uses is a very wasteful operation, and in practice tests should be run to arrive at reduced

working pressures, and consequently cheaper plants, to obtain the desired product direct.

Usual gasoline condensates vary in density from 80°-95° B. (.669-.620 sp. gr.), but the losses sustained by brief exposure to the atmosphere are considerable, often 30-50 per cent. within a few hours. Mixed with refinery distillates the losses are greatly reduced. Valuable tables of evaporation losses of condensates, and condensates mixed with various proportions of distillates, are given in Bulletin 88 of the United States Bureau of Mines already referred to.

The great demand for refinery distillates that could be used for the absorption of the products of gas-gasoline plants was responsible for the big rise in the value of American heavy benzines in 1915-16.

Refrigeration without the aid of compression has been introduced for the treatment of natural gases with some success, but no figures of relative cost are available, and it is doubtful whether such is commercially possible except when the gas is very rich, possibly from wells under low pressure.

Obviously the temperature of the supplied gas influences the output of a plant considerably, and when gas is led in surface mains exposed to the heat of the sun the diminished weight considerably impairs the capacity of the plant during the hours of daylight. A rise of temperature of 50° C. of the gas would in itself represent an 18 per cent. decreased capacity of the plant.

CHAPTER XIII.

COMPILATION OF STATISTICAL RECORDS.

Statistical Records—Drilling Records—Production Records.

Statistical Records.—Petroleum operators should not fail to insist upon the compilation of detailed records of their operations. Unless clear statistical data are regularly collected and preserved, any reorganisations of the staff may lead to erroneous assumptions by new men, and in consequence grave misdirection of expenditure. The character of the collected information must naturally vary in different oil-fields where the conditions bear little resemblance, but in all oil-fields accurate logs of the wells, such as described on p. 317, and details of production and fuel consumption, should be demanded.

Drilling Records.—By skilful application of the data collected from a series of carefully compiled well logs in territories where there is a close resemblance of the geological conditions over the area of operations, it is possible to predict, with close approximation, the rate of drilling at various depths, the amount and size of casing required for lining the well, and the total cost of the well.

In analysing drilling returns it is first advisable to tabulate the data under convenient headings somewhat as follows:—

Number of Well.	Location.	Depth in Feet.	Date Commenced.	Date Finished.	Time Occupied.	Average Feet per Day.	Working Days.	Average Feet per Working Day.
1	...	1,500			60	25.0	55	27.3
2	...	1,430			80	17.9	70	20.4
3	...	1,710			64	26.8	60	28.5
4	...	1,340			50	26.8	42	32.0
5	...	1,650			44	37.5	35	47.2
Average	...	1,526			59.6	26.8	52.4	31.1

PLATE XLI.

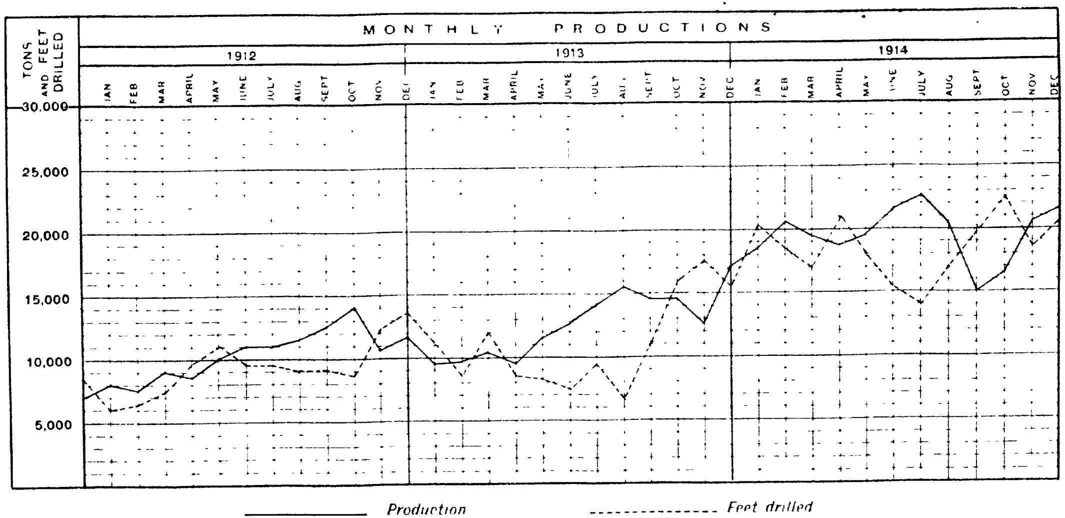


FIG. 146. DIAGRAM SHOWING THE RELATIONSHIP OF PRODUCTION TO DRILLING EFFORT

[To face page 588.

Where different sections of the field disclose distinct features such as increased average depth, especial difficulties due to the need for water exclusion methods, etc., these should be tabulated under different headings. From the above data the average time required to drill wells to an average depth is computed, and the average speed of drilling per diem is found. In extracting the above data from the logs, delays due to exceptional and non-recurring causes quite independent of drilling difficulties should be eliminated, consequently it is advisable to have another column giving either working or drilling days. Applying the assumed data in preceding table it will be ascertained that the time required to drill average wells to a depth of 1,526 ft. will be 59.6 days, a footage of 26.8 ft. per diem, consequently each drilling rig in constant operation should be able to drill 9,800 ft., or 6.4 wells annually.

In many fields, wells are carried to an increased or decreased depth according to their distance from the crest of an anticline or their position with relation to surface contours. In other cases, wells are drilled to different oil horizons, consequently it is sometimes advisable to tabulate the well data under headings, say, wells to 500 ft., 500-1,000 ft., 1,000-1,500 ft., and 1,500-2,000 ft.

Interesting and instructive information will be afforded by comparisons of speed of drilling at different depths. With increased depth there is naturally decreased speed under ordinary circumstances, and by calculating the average daily rate of drilling at intervals of, say, 250 ft., it is possible to plot a curve representing the rate of drilling at any given depth, as in Fig. 148.

On such a diagram may be inserted a number of wells distinguished by some conventional colouring or distinctive method of drawing the curve, or a single line may be left showing average data.

Sudden accelerations or diminutions of speed represented by depressions or elevations of the curve within certain limits of depth will often be observed, and their presence will be traced to such causes as delays in exclusion of water, under-reaming, lowering long strings of casing, specially hard or caving horizons. Occasionally increased drilling speeds are noted in depth due to variations in the nature of the strata or reduced diameter of drilling bit.

Casing used for lining wells may be analysed in the same way as the drilling, and its worth to an oil-field manager will at once be appreciated. From such statistics he will be able to forecast the amount of casing required for temporary use and for permanent insertion in his wells, and so be able to make reliable estimates and prepare trustworthy indents long before the material is needed. Data concerning casing may be conveniently tabulated as below:—

Well No.	Location.	Casing Used in Drilling.											
		12 in.			10 in.			8 in.			6 in.		
		Inserted.	Recovered.	Left in Well.	Inserted.	Recovered.	Left in Well.	Inserted.	Recovered.	Left in Well.	Inserted.	Recovered.	Left in Well.
Average													

For purposes of distinction and comparison casing statistics may be applied to groups of wells of approximately the same depth.

The relationship of production to drilling effort may be diagrammatically expressed in a form (see Fig. 146), months or years being used according to whether the property lies in a quick drilling or slow drilling territory. The diagram attached is based on actual results in an important oil-field, the relationship being correct although the figures are hypothetical.

Drilling progress can be conveniently exhibited and compared at a glance by a diagram such as illustrated in Fig. 147. All wells within the same area are plotted in several colours to avoid possible confusion arising from two or more lines intersecting, such

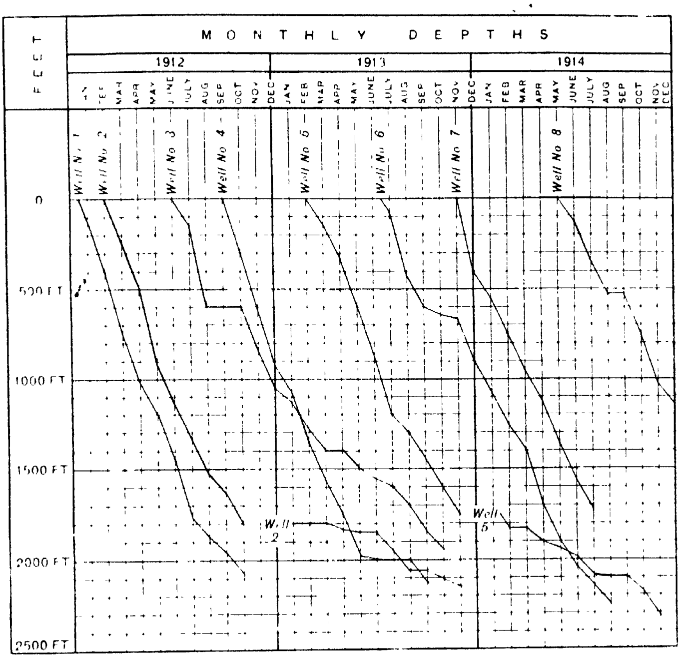


FIG. 147.—GRAPHIC REPRESENTATION OF DRILLING PROGRESS.

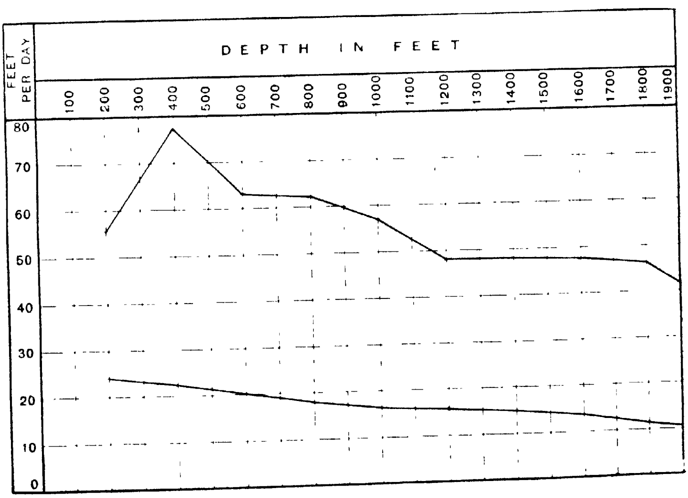


FIG. 148.—DIAGRAM SHOWING THE RELATIONSHIP OF SPEED OF DRILLING TO DEPTH IN TWO TYPICAL OIL FIELDS.

[To face page 590]

s may occur at times through the varying rate of speeds in different wells. This diagram is especially valuable as all the main features of each well are diagrammatically represented. The addition of a few explanatory notes when curves acquire flattened or horizontal courses for unusual periods gives the diagram additional value. A few conventional marks may be arranged to indicate the existence of oil or water sands and the depth of each shoe.

Deepened wells are recognised by their starting point.

Analyses of drilling returns, for the purpose of ascertaining an index of work, must eliminate holidays and time occupied in many subsidiary duties that can, perhaps, never be avoided in practice, but nevertheless constitute no inconsiderable percentage of the time occupied on the well. Time should be expressed in working days, and these latter subdivided into drilling days, if the actual drilling speeds are wanted, quite irrespective of time occupied in lowering columns of casing, excluding water, trial bailing, fishing for lost tools, etc.

Obviously the return of 150 ft. for a month's drilling is no index of the possible rate of drilling if 10-15 days have been spent in fishing operations or on some quite subsidiary non-recurrent operation; consequently comparisons on a drilling-day basis are frequent, but the extent and cause of delays is always chronicled in the log, thereby enabling an analysis of these to be made if they assume unusual or alarming proportions. More than mere academic interest attaches to the analysis of the various operations of drilling if a trustworthy attendant can be induced to submit to the task of detailing the time spent on each. Thus in similar territory there is a close and ascertainable relationship between the time spent in drilling, cleaning, freeing and manipulating casing, etc., which if separated attracts the attention of the management to points that might otherwise escape notice. The use of electrical power is of great service in this respect, as the various duties can be recognised on a power diagram recorded by a watt meter intercepting the current to an electric motor.

The proportionate distribution of cost of wells in different oil-fields varies considerably, as will be seen from the compiled list below, prepared from a few typical wells in the fields under which

they appear. The figures must not be regarded as average examples though typical in the oil-fields named, but they are selected to illustrate the wide differences that exist. Other systems of drilling than those specified may give quite different results. Comparisons of such far-separated fields serve only to satisfy curiosity, as cost of materials, value of labour and fuel, and conditions of work often bear but a remote relationship to one another.

Nature of Expenditure Incurred.	Percentage Distribution of Cost of Representative Wells.							
	Russia.		Roumania.	Galicia.	Burma.	Trinidad.	Peru.	California.
	Baku.	Grosny.						
Labour	36.8	17.9	12.2	38.1	33.3	21.2	21.3	18.1
Casing	42.2	51.6	76.0	42.0	44.5	63.8	45.5	44.4
Fuel	8.4	10.5	4.9	14.6	5.6	5.3	14.8	2.5
Materials / Stores & Sundries	12.6	20.0	6.8	5.3	16.6	9.7	18.4	35.0
Drilling System	Freefall	Wire cable	Canadian cable and rods	Canadian rods and wire line	Cable	Cable	Cable	Cable
Depth of well in ft.	1,800	3,067	1,500	4,000	2,000	1,200	1,250	2,500
Total cost in £	£9,500	£7,800	£2,940	£7,550	£2,400	£980	£440	£4,930
Total cost in $	$45,500	$37,400	$14,200	$36,200	$11,500	$4,700	$2,110	$23,700
Cost per foot in Shillings	105/	51/	39/	38/	24/	16/	7/	39/6
Cost per foot in $	$25.2	$12.2	$9.4	$9.0	$5.75	$3.9	$1.68	$9.5

Production Records.—Daily production statements are imperative on all properties, but the form they partake must necessarily be dependent upon local circumstances which vary so much. The output of small producing wells is generally grouped and measured in a common tank, but where possible the yields of groups of wells should be measured before admitting the oil to the main storage, otherwise the source and cause of a diminished production is difficult to discover.

Wherever possible the yield of individual wells should be measured or approximately estimated daily, and it usually pays to arrange for this or properties where the normal daily yield per well exceeds two or three tons.

Daily returns should be prepared on some such form as the following:—

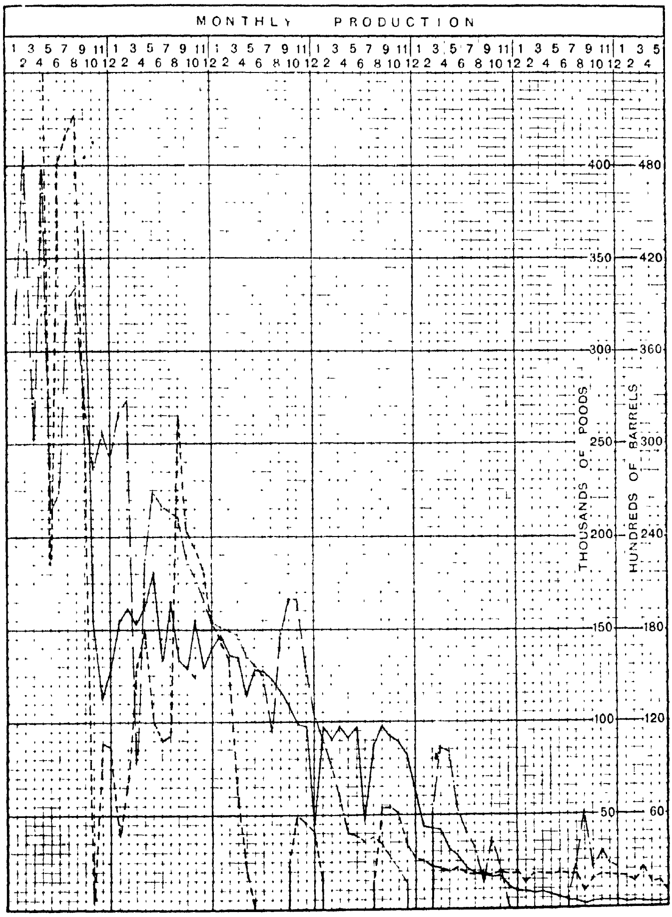


FIG. 140.—PRODUCTION CHART OF A GROUP OF GROSNY (RUSSIA) WELLS.

The diagram shows the irregular production of wells in their early lives, sometimes being out of commission, due to formation of plugs and need for periodical cleaning. The productions apply to equivalent periods of the lives of wells.

[To face page 502.

Form for Group Pumping of Wells.

Section.	Number of Prod. Wells.	Production in........	Fuel Consumption.	Remarks. N.B.—State here cause and duration of any delays, or cause of any diminished yield, or other data of note.
Total -				

Form for Single Well Measurements.

Well.	Section.	Production in	Fuel Consumption.	Remarks. N.B.—State here cause and duration of any delays, and describe any peculiarities exhibited by the Well.
Total -				

Monthly production returns should be more detailed, and bring all information to date somewhat as shown on attached form :—

Number of Well or Section.	Daily Production in ....?																															Total for Month.	Previous Production.	Production to Date.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			
Totals																																		
																																Abandoned Wells -		
																																Grand Total		

Typical Monthly Production Statement.

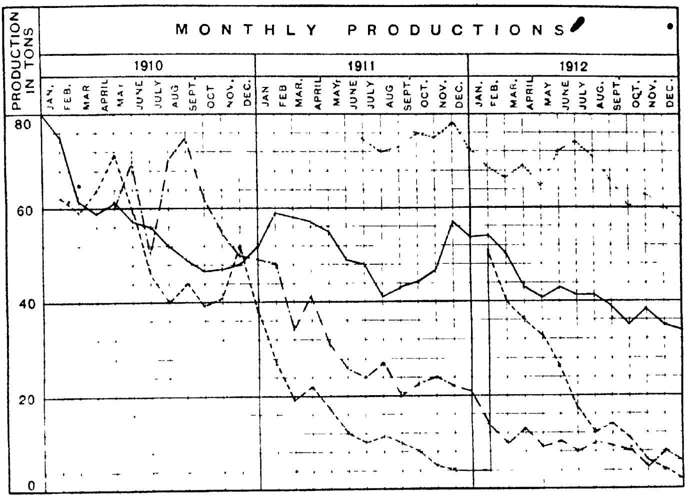


FIG. 150. PRODUCTION CHART OF INDIVIDUAL WELLS

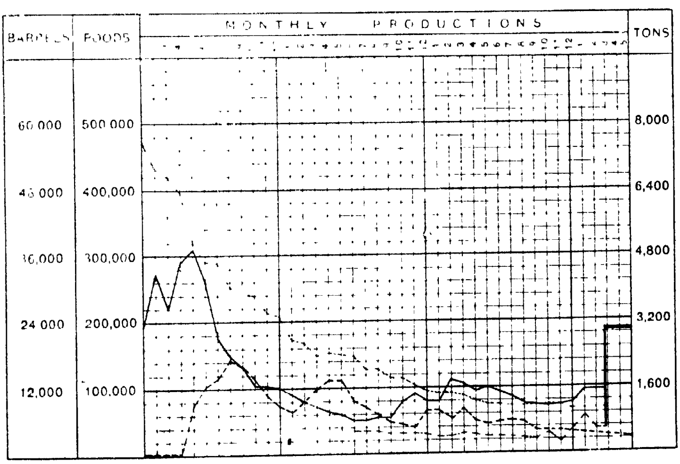


FIG. 151.—CHART SHOWING PRODUCTIONS OF A GROUP OF COMPANIES IN SHIRVANSKY POOL, MAIKOP

(Two months from the end three companies amalgamated.)

[To face page 504

The attached table gives at a glance all the essential details, and enables one to closely compare the relative merits of each well, or group of wells, from month to month to the time of its or their exhaustion or abandonment.

Detailed analyses of the production may be made, and the average production per well calculated in total or pumping days, and inserted if considered desirable. Represented diagrammatically, the daily or monthly productions of wells or groups of wells very distinctly show variations and diminutions of yield. Diagrams may be prepared as Fig. 149, each well curve being plotted in some distinctive colour or form of lining.

Productions may be traced from a common origin if thought advisable when only the number of months in production appear, and a comparison of the yields of wells at equivalent periods of their career may be observed at a glance (see Fig. 150).

Periodical, temporary, but often substantial decreases or augmentations of yields will generally be found to be due to sudden inrushes of sand, where this is a feature, causing first the exclusion and later the freer admission of oil, but frequently causing temporary delays in its extraction. In many fields this irregularity of yield is observed, obstructions of various kinds impeding the free inlet of the oil for a time.

For purposes of estimating future productions based on a fixed programme of drilling, it is necessary to take the average diminution of yield each year, and apply this to new and old wells; thus from data collected over a period of years it may be found that wells yield on an average 30,000 barrels, distributed as follows:—

First year	45 per cent.	=	13,500 barrels.
Second year	22	,,	6,600 ,,
Third year	13	,,	3,900 ,,
Fourth year	10	,,	3,000 ,,
Fifth year, *et seq.*	10	,,	3,000 ,,

In fields where there is no undue congestion or competitive drilling on small areas it is possible from these data to approximately predict the production of any year ahead if the drilling effort is fixed, thus at any date there may be:—

15 wells	between 3 and 4 years old	yielding at rate of	45,000	barrels per annum.
20 ,,	,, 2 ,, 3 ,,	,,	78,000	,, ,,
30 ,,	,, 1 ,, 2 ,,	,,	198,000	,, ,,
10 ,,	less than 1 year ,,	,,	135,000	,, ,,

From the known speed of drilling it will be possible to compute the production from a definite number of wells completed at intervals.

For greater accuracy it is necessary to calculate the monthly percentage of yield, as it is obvious that if a definite number of wells are completed in one year and at regular intervals, no well will yield for the whole year, and many only a small part of the year, but where a regular programme is carried out the completion of wells commenced in the preceding year will neutralise this inconsistency.

It is possible to estimate the approximate drilling effort necessary to sustain or augment a production by ascertaining the exact relationship between drilling and production over a period of years. A diminishing production from a number of oil wells may be reduced or checked entirely by a more active drilling policy; any excess of drilling beyond this latter point will be followed by an increase of production. For example, the completion of ten wells annually 1,500 ft. deep (*i.e.*, 15,000 ft.) may just maintain production at a fixed rate, but every 1,500 ft. drilled above this figure will raise the output by an amount that can be calculated. As development proceeds and the older wells constitute a larger percentage of the total producing wells the amount of drilling needed to sustain a definite production may steadily increase on account of the general loss of gas pressure in the district.

Other factors come into play and need consideration when oil wells are drilled sufficiently close together to drain each other, and when the areas of properties are small and neighbouring operators on one or several sides are actively exploiting their holdings. The more rapid exhaustion of gas pressure reduces the rate of inflow into the wells, and the normal output per well is consequently lowered, for which allowance must be made in preparing forecasts. Impressive and often startling diagrams may be prepared to exhibit the exhaustion, or speaking more correctly the declining productivity of wells under such conditions.

In the chart, Fig. 152, the yields of a group of wells on a rapidly developed field are shown at half-yearly intervals.

The average productions of wells completed in each year are calculated for the same relative period of their age and referred

back to a common origin line. Wells deepened to a new source are regarded as new wells and transferred again to the first line.

A somewhat similar procedure can be adopted to compare diagrammatically the prolific character of different horizons under normal development. Average yields of wells drawing from the same sand have their productions divided into definite periods of time, and these are plotted with reference to the same base line.

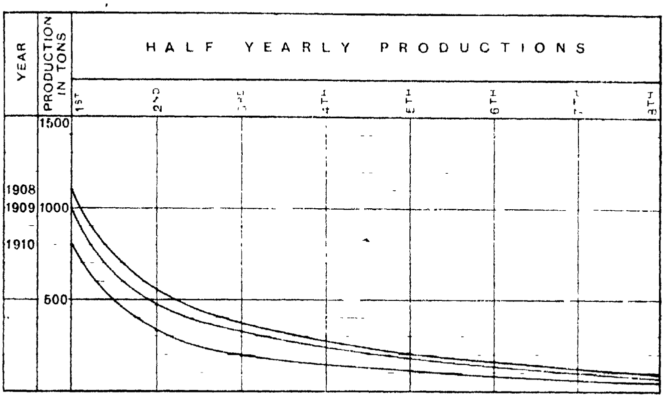


Fig. 152.—Chart showing the Initial Half-Yearly Productions of Wells Completed in Three Successive Years in an Oil-Field where the Rate of Depletion was being Felt.

CHAPTER XIV.

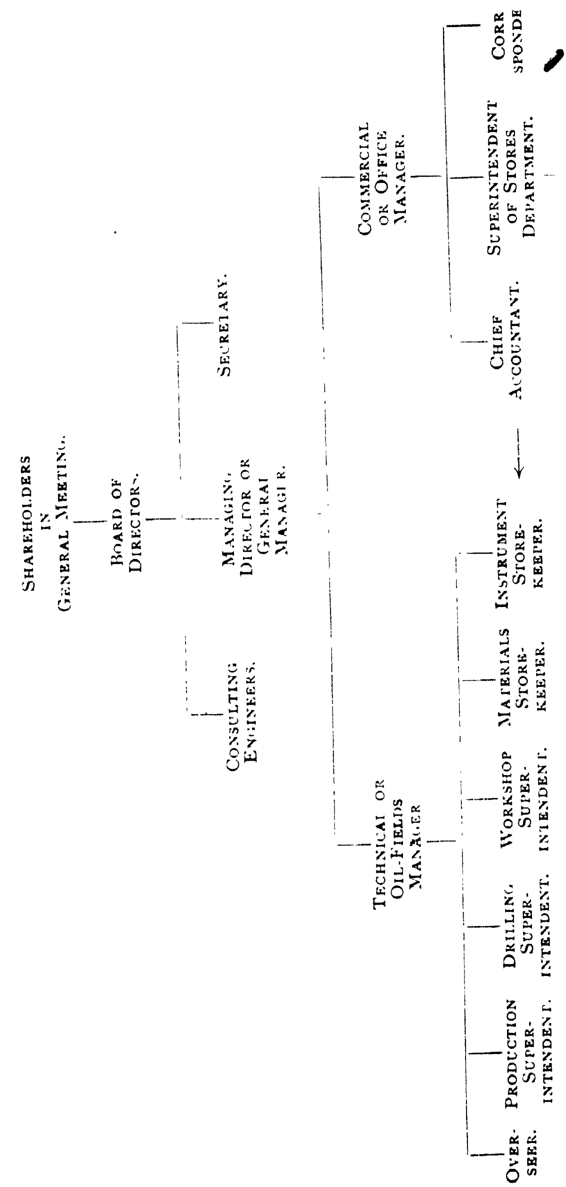
OIL-FIELD ORGANISATION AND ACCOUNTS.

Scheme of Organisation—Technical Organisation—Commercial Organisation.

Scheme of Organisation.—Varied views must naturally be held regarding system of keeping oil-field accounts and records, but the broad principles included in this chapter should not be departed from. In preceding chapters methods of compiling, recording, and analysing statistical and other data are described.

Oil-fields are rarely located near cities, consequently there is only indirect relationships between the shareholders and secretarial department and the oil-field management. This connection is more remote when fields are separated from the central offices by thousands of miles. The general policy of a public company is determined by a Board of Directors, sitting at regular intervals, and they are usually guided in their deliberations by a Managing Director, who keeps a close control of commercial affairs, and a Consulting Engineer or Technical Adviser, who pays periodical visits to the property and closely follows the technical operations. Companies holding large unproven areas often engage a geologist to work up structure, and large concerns sometimes organise a geological department where records are carefully analysed. The diagram opposite indicates the customary departments in an oil-producing company. The Secretary must be conversant with company law and be a qualified accountant, as upon him devolves the whole clerical and financial duties, often necessitating the assistance of a large staff of clerks.

Technical Organisation.—The Technical Manager will carry out the programme of boring and method of exploiting the wells as decided by the local administration, and will, if he be well advised, work in consultation with the senior members of


Shareholders in General Meeting.
Board of Directors.
Managing Director or General Manager.
Secretary.
Consulting Engineers.
Commercial or Office Manager.
Technical or Oil-Fields Manager.
Corr
sponde
Superintendent of Stores Department.
Chief Accountant.
Instrument Store-keeper.
Materials Store-keeper.
Workshop Super-intendent.
Drilling Super-intendent.
Production Super-intendent.
Over-seer.

his staff, *e.g.*, Overseer, Drilling Superintendent, Production Superintendent, and so on.

Overseer.—The Overseer's post is an important one. His duties are to see to the general maintenance of the property in so far as such work does not come directly within the sphere of the various departmental superintendents. It is he who will look to the repair of machinery, pipe lines, roadways, buildings, etc.

Contract Work.—It is a commendable practice in some countries to perform certain duties and special work by contract, as by this means a spirit of competition is created between contractors and one's own men, to say nothing of the additional knowledge gained by a clashing of brains.

The larger contracts, *e.g.*, for drilling and building, will probably be given out by the General Manager in consultation with the Technical and Commercial Managers. Smaller contracts will be given out by the Technical Manager, of course, in consultation with his Departmental Superintendents.

The Drilling Superintendent checks the work done by the Drilling Contractors, and certifies their invoices. Other contract work will probably be followed up by the Overseer.

The invoices, after verification by the Superintendent of the department concerned, are signed by the Technical Manager and sent to the Head Office for payment.

Workshops.—The workshops on the property may include a mechanic shop and foundry, where all boring and fishing tools can be made, or at least repaired, and repairs of machinery undertaken.

Form 1 shows a suitable form to be issued by the various departments on the property to be used for ordering work to be done in the Company's shops.

In the workshops the materials used and time expended on each job will be entered up on a form similar to that shown in Form 2.

These forms, on the completion of each job, are sent to the Accounts Department at the Head Office.

The materials and time will be checked in the Accounts

Department (at the Head Office) with the respective material disbursements and wage sheets. Any difference must of course be explained by the Superintendent of the workshop concerned, and, if the same simply represents waste, this must be written off as a general overhead charge.

The method of costing in the workshops is a question that one cannot deal with in the limited space of one chapter. It is a question that has been treated at great length in many special works issued on the subject. Suffice it to say in the present article that the Technical (or Oil-Fields) Manager should every day see and confirm all orders given by the workshop to the Materials Store, as also all orders for work given by the various departments to the workshops.

Boring.—Each day the Head Drilling Superintendent will collect from each driller or boring contractor his returns for the day, on forms approximating to those on p. 317, which will be handed to the Technical Manager, thence passing to the General Manager.

These returns will be entered up daily into the Boring Journals kept at the Head Office. A separate book may be kept for each well, or a loose-leaf journal kept.

Production.—The distribution of the production amongst the individual wells is practically always a weak spot in oil-fields organisation. In the case of bailing wells, one has to consider the size of the bailing bucket, and the method and speed of bailing, in conjunction with the respective quantities of oil and water in the well. In the case of wells being pumped or worked by air lift, there is probably a possibility of adopting more accurate means, by measuring the oil in tanks, but this of course requires more or less individual attention for each well throughout the whole twenty-four hours of the day. As, however, owing to danger from fire and the necessity for economy in plant, it is generally necessary to take the oil away from the well to some central storage as quickly as possible; it is, as a rule, impracticable to leave the oil in the measuring tanks a sufficiently long time to allow the water to settle off from the oil; furthermore, it is an

Order No. ....

To .... shop

(Date) ....

Quantity.	Measurement.	Weight.

(Signed) .... (Departmental Superintendent)

(Signed) .... (Technical or Oil-fields Manager).

Order No ....

(Date) ....

Date of Completion ....

(Signed) .... (Workshop Superintendent).

MECHANIC SHOP.

Order No.

Order handed in..............................19........

Order completed..............................19........

		Material.						Labour.											
Date.	No. of Requisition of Material.	Description.	Quantity.	Weight		Price.	Amount.	Blacksmith	Strikers.	Fitter.	Turner.	Planing and Slotting	Drilling.	Apprentices.	Rough Labourers.	No. of Wages Sheet	Amount.		Total Cost of Order.
				Cwt.	Lbs														

FORM 2.

expensive system which requires to have men and plant solely for obtaining an accurate measurement of the production from individual wells.

The total production will be measured up daily in a special reservoir kept for this purpose, and then pumped into the stock reservoirs ready for pumping away to the refinery or the purchaser.

The Production Superintendent will then prepare the production returns on the principles outlined in Chapter XIII., and will hand the same for verification and signature to the Technical (or Oil-Fields) Manager, who in his turn will have them sent to the Head Office.

Materials Store.—The Materials Store is a department which requires most close attention. There is probably no part of the business where there can be more leakage, and it therefore behoves the General Manager to see that the most stringent control is kept over all stores.

The organisation of this store is shown under the heading of Stores Department, to which all the materials stores are subordinated.

Instrument Store.—All instruments, plant, and machinery, coming on to, or going out of, the oil-fields, should be passed through the materials store books.

All fishing, boring, and similar tools and instruments are kept in the Instrument Store under lock and key. The Instrument Storekeeper will, of course, keep a complete record of everything in his charge, including the plant and machinery on the property, such as boring rigs, engines, pumps, etc.

An excellent system for keeping a record of the plant and machinery is to have a separate card (Form 3) for each item. This card is self-explanatory.

The various plant and machinery on the property should be actually numbered in nature. This can be done by means of little metal plates fastened to each article, or by stamping. It is preferable to have separate series of numbers for each class of plant, *e.g.*, boring rigs, engines, pumps, lathes, etc.

Hire of Instruments.—In some oil-fields there are concerns

which have special tools, and this requires accurate control, as often large sums are charged for their hire. It is essential that the Instrument Storekeeper should send a report each day of all tools entering and leaving the property. In Forms 4 and 5 are given forms for such reports.

In order that the Oil-Fields Manager may, at regular intervals, have a reminder of what tools remain in the Company's possession, it is advisable that the Instrument Storekeeper should furthermore send, at the close of each month, a list of all instruments remaining at the disposal of the Company on that day. Form 6 is suitable for this purpose.

Commercial Organisation.—On the commercial side of the business the Chief Accountant, the Superintendent of the Stores Department, and the Correspondent will be directly responsible to the Commercial Manager. The Superintendent of the Stores Department will furthermore be responsible for the organisation of the Materials Stores on the various properties.

The Chief Accountant will have control over the correct recording of the Instrument Stores and Plant and Machinery *Accounts Department.* As to the Accounts, there is nothing particular calling for comment, except the question of boring. From a strictly accountancy point of view, the cost of drilling wells should be charged to capital expenditure, as undoubtedly a bore hole is a construction of some degree of permanency, which provides, or should provide, an income. Unfortunately, this degree of permanency is often small, and therefore in capitalising such expenditure one continually finds oneself obliged to write off large sums on the exhaustion or non-productivity of wells. Such expenditure may impose a heavy and unfair burden on the year in which expensive wells happen to end their career; therefore, there is a movement amongst many oil producers in favour of charging expenditure on boring direct to Revenue. It is certainly more prudent, and, after the first initial stages of the exploitation of an oil property, boring and exploitation expenditure will on the whole continue from year to year in more or less regular proportions.

Article No................ *Card No*...............

Description and size ....

Room No..................... *Place No* ....

By whom made or from whom obtained ....

....

(*Date*)......................19

Delivered into Store.			Delivered out of Store.		
Date.	Delivery Note No.	From Where.	Date.	Delivery Note No.	To Whom.

Form 3.

THE MASLO PETROLEUM COMPANY, LIMITED.

PLOT No. III.

Report No. .. ..

TOOLS TAKEN ON HIRE.

....19......

Date.	Period of Hire to Run From			Received From	Description of Tool.	Quantity.	Size.	Measurement.	Price.				Plot No.	Well No.	Remarks.
	Date.	Time.													
		A.M.	P.M.						£	s.	d.	Per			

FORM 4.

THE MASLO PETROLEUM COMPANY, LIMITED.

PLOT No. III.

Report No...................

TOOLS RETURNED FROM HIRE.

.... 19...... .

Date.	Term of Hire Expired on			To Whom Returned.	Description of Tool.	Quantity.	Size.	Measurement.	Plot No.	Well No.	Remarks.
	Date.	Time.									
		A.M.	P.M.								

THE MASLO PETROLEUM COMPANY, LIMITED.

PLOT No. III.

STATEMENT OF TOOLS HIRED.

For the Month of....................19.........

Remarks.	In the Possession of the Company at the Beginning of the Month.	Received During the Month.	Returned During the Month.	In the Possession of the Company at the End of the Month.	Remarks.

FORM 6.

Stores Department.—The question of the Stores Department, the Superintendent of which will be stationed in the Local Office, is a serious one. This employee will be trusted with the organisation of the various Materials Stores on the Company's property.

There is no department where, in the absence of a suitable superintendent and organiser, more leakage and waste can take place. The Superintendent must be a man of indisputable integrity, minute accuracy, and highly informed in regard to the sources, quality, and prices of materials.

To obtain an adequate control of prices the Stores Superintendent will be well advised :—

(1) To have his own series of printed forms (generally booklets) for price lists—a separate form for each category of material. These forms should be sent round to suppliers from time to time, so that the latter may fill in their prices.

(2) To have the prices entered upon cards kept in a suitable card cabinet (see Form 7). Entries should be made in pencil, as they will naturally have to be altered from time to time.

A great economy of work can be effected by the following system of issuing orders for materials:—

A separate requisition for each item is written by the Materials Storekeeper at the property in four copies (by means of carbon papers) as follows:—

a. Requisition addressed by the Head Office to Supplier (Form 8).

b. Requisition addressed from Property to Head Office (Form 9).

c. Delivery Note (Form 10).

d. Counterfoil for use of Materials Stores (Form 11).

The Form *b* is signed by the Oil-Field Manager, Overseer, and Materials Storekeeper, and then sent together with Forms *a* and *c* to the Head Office.

These forms are originally bound up in books in the order shown above. Forms *a*, *b*, and *c* are perforated at the sides, whilst the counterfoil remains permanently in the book, and serves as a permanent record for the Materials Storekeeper.

To get a good impression from the carbon papers, the requisition may be written with a marking-ink pencil.

The forms of requisition "from Head Office to" (*i.e.*, *a*) is placed on top of the series, the same being the document that serves as a voucher for an outside firm, and as such should be as indelibly written as possible.

The last two columns on Forms *b* and *c*, viz., "For what purpose required" and "Balance in hand," will be filled in on Form *b*, as there are, of course, no corresponding columns on Form *a*.

TUBES, GAS.

Sizes.	Evans & Piggott.		J. K. Smith.		Williams & Co.		Earlswood Tube Co. Ltd.		F. B. Jones.		Collingwood & Thom.	
⅛ in.		1½		1¼		1¼		1¾		1½		1½
¼ ,,		2		1¾		1¾		2		1¾		1¾
⅜ ,,		2½		2		2		2½		2¼		2
½ ,,		4		3½		3¼		3½		3		3½
¾ ,,		6		5		4½		4¾		4		4
1 ,,		8		7½		7		7		6½		7
1¼ ,,		10		10½		9½		9½		9		9½
1½ ,,	1	...	1	1		11		11¾		11	1	1
1¾ ,,	1	2	1	3	1	1	1	2¼	1	2	1	2
2 ,,	1	3	1	5	1	3	1	3½	1	5	1	5
2¼ ,,	1	6	1	9	1	6	1	8½	1	8	1	6
2½ ,,	1	9	2	...	1	10	1	11¾	2	...	1	11¾
3 ,,	2	2	2	6	2	3	2	4¾	2	5	2	5
3½ ,,	2	6	2	9	2	8	3	¾	2	10	3	...
4 ,,	3	...	3	3	2	11	3	7¾	3	1	3	3
5 ,,	4	6	4	9	4	9	5		4	11	4	9
6 ,,	5	6	6	...	5	9	7		5	6	5	6

FORM 7.

After requisition *b* has been approved by the General Manager the name of the intended supplier is filled in on requisition *a* (Form 8) by the Superintendent of the Stores Department at the Head Office, and together with delivery note *c* (Form 10) handed to the supplier. Requisition *b* is retained in the Head Office.

The Superintendent of the Stores Department arranges for the dispatch of goods from the supplier in accordance with the requisition *a*. On delivery the carters bring back to the Superintendent of the Department the Delivery Note (Form *c*), duly completed (or corrected, if necessary).

The supplier's Delivery Notes are sent with the materials to the property.

The Delivery Notes *c*, filled in by the suppliers, are checked in the evening with the property requisitions *b*.

It is essential that there should be but one channel of entry for all materials, plant, or machinery of any sort coming into the Company's possession, and that should be the Materials Store. Organisations exist under which it was the Instrument Storekeeper's duty to give receipts and issue returns for plant and machinery, whilst the Materials Storekeeper received the ordinary materials. The result is that when some day certain goods are delivered to the property, both the Storekeepers claim the articles for their own, and both issue receipts and returns for the same, with the result that the mistake is overlooked in the Accounts Department, and the goods may be paid for twice over.

All materials received in the stores are entered in a receipt book in four copies:—

a. Receipts (Form 12).
b. Returns (Form 13).
c. Copy of Receipts (Form 14).
d. Counterfoil (Form 15).

These are also all obtained at one writing by means of carbon papers. These forms are made up in book form in a similar way to that obtaining with the requisitions.

Forms *a*, *b*, and *c* are perforated; *d* remains permanently

In the event of goods being delivered of quality or sizes which do not correspond with the terms of this requisition or with samples provided by the supplier, the latter must take the said goods back and reimburse Company for all losses arising from such incorrect delivery, and the Company reserves to itself the right to cancel this requisition without any liability whatever towards the supplier. In the event of the supplier delivering a larger quantity of goods than requisitioned, the Company has the right to reject the surplus and all losses arising from the delivery of the surplus will be borne by the supplier.

In the event of the Company giving the supplier a sample, such sample must be returned to the Company with the first consignment of such goods supplied.

Immediately on delivery of the goods delivery notes with prices must be given to the Superintendent of the Stores Department at the Head Office.

Acceptance of goods takes place exclusively on the oil-fields.

A receipt for the goods shown in this requisition must be obtained by the supplier from the store to which the goods were delivered.

In the event of a receipt not being given for the goods, the supplier is to notify the Company in writing within two days of delivery of the goods.

The present requisition can in no case serve as proof of the receipt by the Company of the goods shown in the same.

Invoices for the goods delivered to the Company must be handed in to the Head Office not later than the 5th of the month following receipt of the goods.

Payment per invoices delivered after the 5th of the month will be postponed to the following month.

On the invoices the supplier must show the number of each receipt (for goods) and from which store such receipt is given.

On settlement of the invoice all receipts for goods must be handed in to the Head Office.

Invoices for goods delivered without a written requisition from the Head Office of the Company will not be accepted; therefore suppliers are requested to see that goods are only delivered on the basis of such requisitions.

THE MASLO PETROLEUM COMPANY, LIMITED.

PLOT No. III.

Requisition No.......................

From the Head Office of..............................

To..19........

Description of Goods.	Quantity.	Weight.	Measurement.	Price.	Remarks.

FORM 8.

THE MASLO PETROLEUM COMPANY, LIMITED.

PLOT No. III.

Requisition No...... ....

From the Oil-Fields Office to the Head Office.

...............................19.........

Description of Goods.	Quantity.	Weight.	Measurement.	Notes Made at Head Office.			For What Purpose Required.	Balance in Hand.
				To Whom Order Given.	Price.	No. of Returns.		

FORM 9.

THE MASLO PETROLEUM COMPANY, LIMITED.

DELIVERY NOTE.

To Requisition No..............

From..

To the Oil-Fields of the Maslo Petroleum Company, Limited.

................................19.........

Description of Goods.	Quantity.	Weight.		Measurement.		Price.		Amount.		No. of Materials Returns.

FORM 10.

THE MASLO PETROLEUM COMPANY, LIMITED.

PLOT No. III.

Counterfoil of Requisition No...........

From the Oil-Fields Office to the Head Office.

................................19.........

Description of Goods.	Quantity.	Weight.		Measurement.		No. of Returns.	Notes.	For What Purpose Required.	Balance in Hand.

FORM 11.

in the book. The receipt is placed first in the series, so that as in the case of the requisition, the most indelible impression is given on the form that serves as a voucher for the supplier. Of these, the receipt *a*, and copy of receipt *c*, are handed to the carrier. The carrier has to take the same to the supplier of the goods, who endorses on the copy *c* that he has received the original receipt *a*, and only on the presentation of such signed copy of receipt *c* is the carrier paid for the cartage.

Invoice No.......

THE MASLO PETROLEUM COMPANY, LIMITED.

PLOT No. III.

Goods Receipt No...........

Received from..

....19.....*per delivery note No*.........

Name of carter...

No. of Requisition.	Description of Goods.	Quantity.	Weight or Measurement.	Notes of Head Office.	Notes.

No. of carts...........

Storekeeper (signature)..

Without presentment of this receipt settlement will not be made on the invoice.

For the Head Office. ***Invoice No.*....

FORM 12.

THE MASLO PETROLEUM COMPANY, LIMITED.

PLOT No. III.

Returns No............

Goods received from..

Delivered on................................19........per delivery note No.........

Name of carter...

No. of Requisition.	Description of Goods.	Quantity.	Weight or Measurement.	Price.	Per Unit.	Amount.	Dis-count.	Notes.

No. of carts...........

The goods shown in these returns were accepted by (Storekeeper)................................

Acceptance sanctioned by (Oil-Fields Manager)..

The present document cannot serve for the supplier as proof of delivery of the goods.

FORM 13.

COPY. *Invoice No.........*

THE MASLO PETROLEUM COMPANY, LIMITED.

PLOT No. III.

Copy of Goods Receipt No......................

Received from...

....................................19........*per delivery note No.........*

Name of carter...

No. of Requisition.	Description of Goods.	Quantity.	Weight or Measurement	Notes of Head Office.	Notes.

No. of carts.................

Storekeeper (signature)...............................

Original goods receipt received (signature of supplier)................................

The present copy of goods receipt is only intended for the carter and cannot serve for the supplier as proof of delivery of the goods.

FORM 14.

THE MASLO PETROLEUM COMPANY, LIMITED.

Invoice No.......

PLOT No. III.

Counterfoil of Returns No.....................

Received from.................... ...S..................................

....19.........*per delivery Note No.*.........

Name of carter...

No. of Requisition.	Description of Goods.	Quantity.	Weight or Measurement.	Card No.	Invoice No.	Remarks.

No. of carts..................

Storekeeper..

FORM 15.

The object of this system is obvious. One thus sees tha the supplier has a receipt bearing the signature of the stor requisitioned, the material in question, and the whole responsi bility for the delivery of the receipt to the supplier is throwı on the man actually delivering the materials in such a thoroug manner that he is likely to fulfil his duty, for otherwise h (the carter) is not paid for delivery.

With some firms it is the custom for a materials depart ment clerk to give a receipt at the Supplier's Store, and th receipt from the Company's Store is then sent direct to th Superintendent of the Stores Department. This, howevei necessitates very close and prompt attention on the part of th Stores Department in checking up separate series of receipts and it can very well happen that a supplier may one da present a receipt given for materials by the Head Offic Clerk, whilst the materials cannot be traced to any of th Company's Stores. If, as is sometimes the case, such a mis take is only discovered after the lapse of several months, i may prove impossible to trace the destination of the materia whilst the supplier all the same has to be paid.

The returns *b* with the signature of the Materials Store-eeper and Property Manager, are sent to the Stores Depart-ient at the Head Office, and there checked with the requisitions nd delivery notes (as above mentioned), prices being duly lled in and checked by the Superintendent of the Department.

In the above-mentioned receipts, returns, etc., are shown he numbers of supplier's delivery notes and numbers of equisitions.

Suppliers when sending in their invoices must also return ıll requisitions. The invoices are checked by the Stores Department with the above-mentioned returns *b*, and then ıanded to the Accounts Department.

Payment is not made on invoices until the receipts given ɔy the Materials Storekeeper for the materials are returned by he Supplier to the Accounts Department at the Head Office.

For materials received back from the oil-fields into the Materials Store receipts are also given from the above-mentioned ɔook to the Superintendent of the Department concerned.

The counterfoils of the returns are checked by the Materials Storekeeper with the property requisitions, the numbers of the requisitions being shown on the returns, and vice versa. In this way he keeps an immediate control over the fulfilment of orders by the Stores Department.

All plant and machinery received is immediately handed over to the Superintendent of the Instrument Store.

For all materials taken from the store, requisitions have to be presented signed by the head of the department in question. Record of the same is made on special Materials Disbursement Returns. These are written in duplicate, the second copy (counterfoil) being obtained by means of carbon paper (see Form 16). They are, of course, also numbered consecutively. The numbers of the requisitions received from the various superintendents are shown in the returns against the items concerned. For the materials delivered to the property, separate disbursement returns are written for each department, and signed by the Storekeeper, the Overseer, the Receiver of the goods, and the Oil-Fields Manager. To all returns for goods delivered to

outside persons, or returned to the dealers, receipts from the persons concerned are attached, whilst the returns are only signed by the Stores Superintendent, the Overseer, and Oil-Fields Manager.

When, after a receipt has been given for materials, the said materials have to be returned for some reason or other, such materials must be written off in the disbursement returns, the latter entry being accompanied by a receipt signed by the dealer in question; only on this condition should such a disbursement be recognised by the Accounts Department.

The Materials Storekeeper, in place of the ordinary materials waste or day book, will have the counterfoils of the receipts and disbursement returns respectively.

Records of stocks are kept on the card system (Form 17) (see p. 622).

For each item delivered a fresh card is started, and each disbursement of such material is shown on the card in question until the supply is exhausted, when the card is transferred into a separate box for "dead" cards.

It follows that just before each card is finished a fresh card will have been opened for the next delivery of the article in question, which card in its turn will be written off in the same manner.

The advantage of this system is its simplicity, in that practically no additions or subtractions are required.

It will be seen from the foregoing outline that each item is written out not more than twice. No writing is done in the Stores Department at the Town Office at all beyond the entry of the prices into the card cabinet, the supplier's name on the requisitions *a* (Form 8), and filling in the column: "Notes made at the Head Office" on requisitions *b* (Form 9). The Storekeeper writes each item requisitioned once, each item received twice (*i.e.*, once on the receipt form and once in his card register). Similarly with disbursements, the items are entered by the Storekeeper once on the disbursement form and once in the card register.

It must be borne in mind that the essence of good organisa

THE MASLO PETROLEUM COMPANY, LIMITED.

PLOT No. III.

Disbursement Return No...........

Delivered to...

Requisition No.	Where Delivered.	Description of Articles.	Quantity.	Weight.	Measurement.	Price.	Per	Amount.	Remarks.	Folio.

FORM 16.

tion is simplicity; the more copying out of items the more chance of mistakes. If, with the above system, where each item, one may say, is not recorded more than twice in the Stores Department and Stores, there is one mistake in every 1,000 entries, then with many systems, where one and the same item is written up ten or even more times (which is by no means exceptional), such chances of mistake are proportionally multiplied.

Series No................... *Card No.*....................

Room No..................*Place No.*..................*Normal Stock*..................

Received from ....

....(*Date*)..................19.........

Delivery Note No...................*Receipt No.*....................

Quantity............ .*Weight* ....*Measurement*....................

Disbursements.					Balance in Hand.		
Date.	Returns No.	Requisition No.	Quantity.	Weight or Measurement.	Date.	Quantity.	Weight or Measurement.

FORM 17.

APPENDIX.

DIVINING FOR PETROLEUM.

THE subject of prospecting would perhaps be incomplete without reference to "Divining." During the last few years diviners have appeared who claim the power of tracing oil by means of a metal wire or hazel twig. Exponents of the art claim that when passing over oil their wands are deflected in varying degrees. The wire is held in the same way as the hazel twig by a water diviner, that is, in an exceedingly sensitive state by which any contraction, even unconscious muscular contraction, causes a considerable movement of the twig. Diviners' twigs show certain liveliness in the hands of the author, but he would hesitate to attribute their movements to anything beyond muscular effort, even if involuntary. Operators will need some very definite evidence before expending their funds on sites chosen by diviners. More ambitious is an instrument with a needle for which claims are made, but the makers decline to allow the apparatus to be tested in an oil-field before purchase.

AREA PER WELL FOR VARIOUS SPACINGS.

Assuming wells to draw from an equal radius around, the table below gives the approximate acreage per well for different spacings set out in equilateral triangles:—

Distance Apart.	Area per Well.	Distance Apart.	Area per Well.
100 feet.	.18	400 feet.	2.9
150 „	.4	450 „	3.7
200 „	.7	500 „	4.5
250 „	1.1	600 „	6.5
300 „	1.6	700 „	8.8
350 „	2.2	800 „	11.5

MEASURES AND USEFUL FIGURES.

Russian Measures.

1 vershok = 1.75 in.				
16 „	= 1 arsheen = 2 ft. 4 in.			
48 „	= 3 „	= 1 sajene = 7 ft.		
24,000 „	= 1,500 „	= 500 „	= 1 verst = 0.663 mile.	

2,400 sq. sajenes = 1 dessiatine = 2.6997 acres.
250,000 „ = 1 sq. verst.

1 vedro = 2.7069 Imperial gals. = 3.24 American gals.

40 foonts (pounds) = 1 pood = 36.1141 lbs. English.
62.2 poods = 1 ton.

1 rouble at normal periods, about 2 shillings or 48 cents.

Roumania.

Pogon = 1.235 acres = 0.5 hectare.
Metric tons and cars of 10 metric tons.
Lei = about 1 franc = 10 pence = 20 cents normal times.

Galicia.

Joch = 1.422 acres.
Metric tons and cars of 10 metric tons.
Kronen = about 1 franc = 10 pence = 20 cents at normal times.

Burma.

Viss = 3.65 lbs. av. 100 viss oil = approximately 1 barrel.
1 anna = 1 penny = 2 cents, 1 rupee = 16 annas.

METRIC SYSTEM.

Metre = 39.3704 in. = 3.2808 ft. Millimetre, about $\frac{1}{25}$ in. Kilometre, 0.6213 mile.

Square metre = 1550.03 sq. in. = 10.7641 sq. ft. = .000247 acre. Sq. kilom. = .3861 sq. mile.

Hectare, 107,641 sq. ft. = 11960.1 sq. yds. = 2.47110 acres.

Litre = 61.0254 cub. in. = .22 gal. Imperial = .264 gal. American.

Gramme = 15.432 grains. Kilogramme, 2.2046 lbs.

Franc = 10 pence = 20 cents normal times.

UNITED STATES AND BRITAIN.

1 acre = 4,840 sq. yds. = 43,560 sq. ft.

1 cub. ft. = 7.48052 United States gals. = 6.23210 Imperial gals.

TEMPERATURE CONVERSION.

F. to C.	- -	$C.^\circ = \frac{5}{9}(F.^\circ - 32^\circ)$
F. „ R.	- -	$R.^\circ = \frac{4}{9}(F.^\circ - 32^\circ)$
C. „ F.	- -	$F.^\circ = \frac{9}{5}C.^\circ + 32$
C. „ R.	- -	$R.^\circ = \frac{4}{5}C.^\circ$
R. „ F.	- -	$F.^\circ = \frac{9}{4}R.^\circ + 32$
R. „ C.	- -	$C. = \frac{5}{4}R.^\circ$

USEFUL CONVERSION FIGURES.

Metres × 3.281 = feet. Feet × 0.3048 = metres.

Square metres × 10.764 = square feet. Square feet × 0.09308 = square metres.

Gallons × 4.546 = litres. Litres × 0.21998 = gallons.

Gallons (Imperial) × 1.2012 = United States gallons. United States gallons × 0.83226 = Imperial gallons.

Useful Conversion Figures—*continued.*

1 barrel of 42 United States gallons = 1 barrel of 35 Imperial gallons, ratio therefore 6 : 5.

1 gallon oil = ($10 \times$ specific gravity) lbs.

1 barrel oil = ($350 \times$ specific gravity) lbs. $= \frac{350 \times \text{sp. gr.}}{2240}$ tons $= \frac{350 \times \text{sp. gr.}}{2200}$ metric tons.

1 ton oil $= \frac{2240}{350 \times \text{sp. gr.}}$ barrels $= \frac{2240}{\text{sp. gr.} \times 10}$ gallons $= \frac{2240}{62.425 \times \text{sp. gr.}}$ cubic feet.

1 cubic foot oil $= \frac{62.425 \times \text{sp. gr.}}{2240}$ tons.

Lbs. per square inch $\times$ 2.326 = foot head of water. Feet of water head $\times$ 0.43 = lbs. per square inch.

Inches water gauge $\times$ 0.0358 = lbs. per square inch.

INDEX.

Paragraph headings are put in bold type.

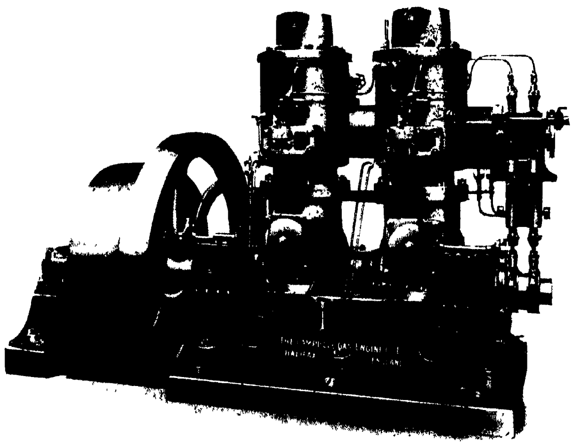
Printed at The Darien Press, *Edinburgh.*

CAMPBELL

VERTICAL OIL ENGINES

Two-Cycle (Semi-Diesel) Type

From 5 to 350 B.H.P.



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These are the simplest Oil Engines made, and have the least possible number of moving parts. They run on Kerosine, Gas Oil, Shale Oil, or Crude Petroleum. No Lamp is required while running. Fitted with Forced Lubrication to Cylinders and enclosed bearings.

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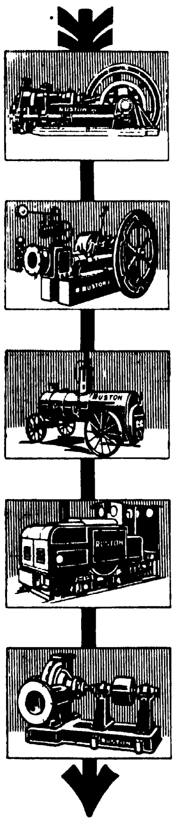

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